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ABSTRACT

The research was concerned with the experimental use of Model II of the Instantaneous Pitch-Period Indicator (IPPI) with deaf subjects, and with the design and construction of a portable unit. Deaf adults and deaf children participated in training programs designed to develop more effective patterns of speech using the IPPI for visual monitoring of intonation usage. The deaf adults' study suggested equipment modifications, teaching materials, and research design for the children's study. The children's study revealed that deaf children improved during training with the IPPI, most noticeably during the first 4 weeks of the 8-week program. Resulting data on the sequence of rhythm and intonation learning tasks were incorporated into an expanded training program, and new features were designed and constructed into apportable unit designated as Model III, Instantaneous Pitch-Period Indicator: Amplitude, Intensity, Duration (IPPI-AID). (Author/JD)

ED041430

Teaching of Intonation Patterns to the Deaf Using the Instantaneous Pitch-Period Indicator

by

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VRA Grant 2360–S

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February 28, 1969

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SIGNIFICANT FINDINGS FOR THE REHABILITATION WORKER

1. Methodology. The Instantaneous Pitch Period Indicator was used by a group of deaf adults and a group of deaf children for self-monitoring of vocal pitch during a training program designed to improve each subject's intonation patterns of speech. The training program for children was modified on the basis of results of the adult study. Listener panels judged the relative effectiveness of pitch usage from tape recordings made before, during, and after the training program.

2. Findings. While the program designed for deaf adults showed minimal improvement, the experience resulted in a greatly modified program for children involving sequential training in rhythm, pitch patterns and intonation. The children showed significant improvement in sequential learning of skills during the program. A new unit, the Instantaneous Pitch-Period Indicator: Amplitude, Intensity, Duration (IPPI-AID) has been constructed utilizing the results of the experimental training programs.

3. Implications. The visual feedback process of the Instananeous Pitch-Period Indicator provides significant motivation for deaf adults and children to improve speech. It also provided instantaneous feedback of successes in vocal performance. The training program must be designed to provide sequential teaching and reinforcement of speaking skills which deaf individuals can perform successfully. The teaching programs developed for visual feedback systems have implications for other speech training systems that do not use such equipment.

4. Recommendations. Research on developing training programs and visual feedback equipment should be continued, with funds made available for construction of additional units and wider use of the equipment in programs for the deaf.

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TEACHING OF INTONATION PATTERNS TO THE DEAF USING THE INSTANTANEOUS PITCH-PERIOD INDICATOR

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PAPERS PRESENTED DURING GRANT PERIOD

1. Dolanský, L., "Pitch Extraction and Display for the Deaf," Paper P-O-1, 6th International Congress on Acoustics, Tokyo, Japan, August 21-28, 1968.

2. Phillips, N. D., Remillard, W., Bass, S., Pronovost, W., Teaching of Intonation to the Deaf by Visual Pattern Matching," presented before the Conference on Speech Analyzing Aids for the Deaf, Hearing and Speech Center, Gallaudet College, Washington, D. C., June 14-17, 1967. Also published in American Annals of the Deaf, Vol. 113, No. 2, pp. 239-246, March, 1968.

3. Phillips, N. D., "Detection of the Voice Fundamental for Visual Pitch Display," presented at the Seventy-fifth Meeting of the Acoustical Society of America, Ottawa, Ontario, Canada, 21-24 May. 1968.

4. Pronovost, W., "Visual Monitoring of Speech by the Deaf," V Congress of the World Federation for the Deaf, Warsaw, Poland, August, 1967.

ABSTRACT

This research was concerned with the experimental use of Model II of the Instantaneous Pitch-Period Indicator (IPPI) with deaf subjects, and with the design and construction of a portable unit for future use. Experimental groups of deaf adults and deaf children participated in training programs designed to develop more effective patterns of speech using the IPPI for visual monitoring of intonation usage.

The major contribution of the deaf adult's study was to suggest equipment modifications, teaching materials and research design for the children's study. The children's study revealed that deaf children improved during training with the IPPI. Improvements were most noticeable during the first four weeks of the eight-week experimental program. The study also provided data on the sequence of rhythm and intonation learning tasks to be incorporated into an expanded training program.

As a result of the experimental studies, new features have been designed and constructed into a portable unit designated as Model III, also called IPPI-AID, (Instantaneous Pitch-Period Indicator: Amplitude, Intensity, Duration).

I. INTRODUCTION.

Interest in the use of equipment which provides visual displays of acoustic parameters of speech as instruments for teaching speech to the deaf has increased in recent years, as evidenced by the Conference on Speech-Analyzing Aids for the Deaf held at Gallaudet College, June 14-17, 1967 [29]. Over one hundred persons, including twenty from Europe, Japan and South Africa, attended the conference to hear technical papers and observe demonstrations of equipment, much of which had been brought from Sweden, Denmark and parts of the United States. Technological developments have resulted in the construction of many units that provide visual displays of speech information; some of these can be operated easily by teachers in classrooms of deaf children.

The potential for increased availability of visual aids for speech development and correction has raised questions concerning the efficacy of such equipment for teaching speech to the deaf. Some of these questions are: Can deaf children and adults utilize visual displays of speech information to monitor their own speech production? Will the speech of deaf individuals improve more significantly when visual monitoring equipment is used than when other methods of teaching speech are used? What types of teaching procedures and programs are required when visual feedback equipment is used? What technical design features provide for the most efficient use of equipment by deaf individuals and their teachers?

Research efforts by Kopp and Kopp [18], Dolanský et al. [7, 8] and Pronovost et al. [32] provide data to indicate that visual displays can be used by normally hearing and deaf children and adults to monitor their speech productions. Data from these studies show also that changes do occur in the speech patterns of deaf children during experimental programs, although the extent to which the changes in speech resulted from the visual monitoring process can only be inferred because of the many variables present in the total teaching programs. The study by Dolanský, Karis, Phillips and Pronovost [8] did involve a fairly carefully controlled experiment with normally hearing adults, who were able to learn to produce vocal pitch patterns by means of visual stimuli and visual monitoring. The equipment used in the study could be operated with relative ease. Results were sufficiently encouraging to proceed with research with deaf individuals.

II STATEMENT OF THE PROBLEM

The present research is concerned with the use of the Instantaneous Pitch-period Indicator (IPPI) with experimental groups of deaf adults and children. The purposes of this research were to:

1. Refine the design of the equipment as a result of the study of normally-hearing adults and construct a unit for experimental studies.
2. Design a teaching program for use of the IPPI in improving intonation patterns of deaf adults and study the effectiveness of the program.
3. Design a teaching program for use of the IPPI in improving intonation patterns of deaf children and study the effectiveness of the program.
4. Refine further the design of the equipment and construct a portable unit for use in classrooms of schools for the deaf.

III. REVIEW OF RELATED LITERATURE.

A. Previous Research with the IPPI

1. Initial Research

In the course of speech-analysis studies, pursued almost without interruption since 1952, Dolanský developed the original "Instantaneous" Pitch-period Indicator [5]. This device is capable of indicating the beginning of a new pitch period by means of a pulse which occurs near the beginning of the pitch period (see Fig. 1b). The pitch-period indicator pulse can then be used to start a constant-slope waveform each time the pulse occurs (see Fig. 2). The end of this sloping line just before a new one starts can be used as an indicator of the fundamental (pitch) frequency of the voice. When the triangular waveform is compressed in the horizontal (time) direction (Fig. 3), a shadowgraph results and the edge of the shadowgraph is seen to represent the fundamental frequency. Although the device was originally developed for other purposes, it has been later demonstrated that it can indicate variations in pitch, and thus can be used for establishing the necessary feedback in teaching proper inflections when normal hearing is either impaired or non-existent, and thus cannot supply the necessary correcting feedback information to the subject.

2. Survey of Pitch-extraction Techniques

As a part of a survey report on Speech Analysis [6], the problem of pitch and speech communication was studied and the various methods of pitch extraction compared. These studies were later updated during Dolanský's sabbatical-year research in Stockholm (see Sec. III-A5).

3. Study of Larynx Signals

From 1962 to 1964, as principal investigator of the NSF Grant GP-590 on "Fundamental Characteristics of Larynx Signals in Speech-signal Communication", Dolanský directed various larynx-signal studies as reflected by the following list of MS theses supervised by him during this period:

Howard, Calvin R., "Real-time Measurement of Pitch Perturbations"

Megna, Joseph A., "A Pitch-period Reiterating Speech-compression System"

Michaels, Sheldon B., "Detectability of Missing Pitch Periods in Speech"

Shaffer, Harry L., "Information Rate Necessary to Transmit Pitch-period Duration Values for Connected Speech"

Vezza, Albert, "Mathematical Analysis of the Glottal Waveform"

Wallace, John C., "Evaluation of Pitch-extraction Methods and their Relation to Synthetic Speech and Naturalness"

More recently supervised theses include the following:

Phillips, Nathan D., "Visual Display for Pitch Communication" (MS thesis)

Beninghof, William Joseph, "A Functional Analogy between Space and Color Perception and Its Implementation for Sensory Replacement" (PhD thesis)

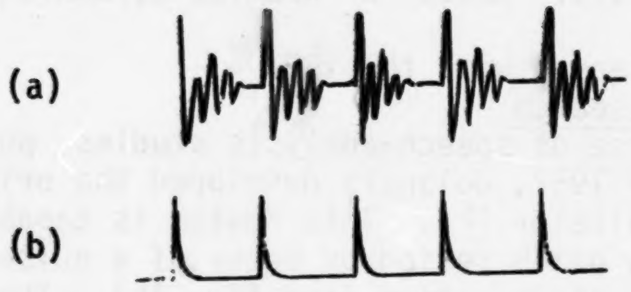


Fig. 1. Waveform of (a) the voiced speech sound [u], and (b) pitch-period indicating pulses derived from the same signal.

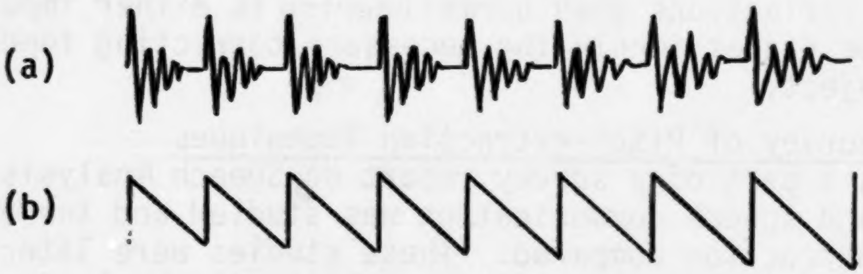


Fig. 2. Speech waveform (a) and the corresponding triangular (constant-slope) waveform (b).

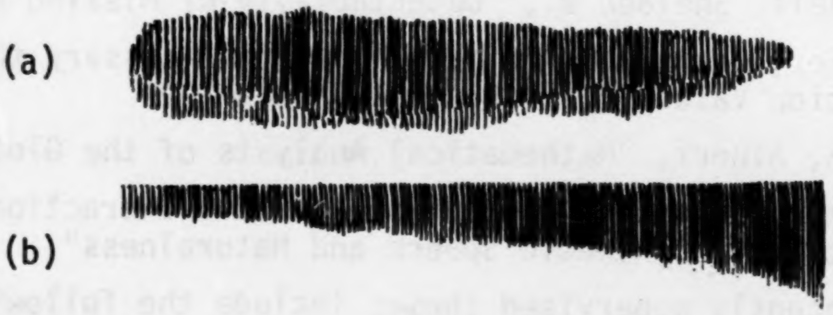


Fig. 3. Display resulting from horizontally compressing the display of Fig. 2. The lower edge of (b) represents the pitch frequency vs. time.

4. Communication of Pitch Information to Deaf Children

In 1965, as principal investigator of U. S. Office of Education Cooperative Research Project No. S-281, Dr. Dolanský directed a pilot study on teaching deaf children to approximate the teacher's pitch pattern. The results, based on a very limited number of profoundly deaf children and instructional lessons, indicated that (a) the children do follow the general pattern of the stimulus after some practice, (b) with respect to pitch-pattern imitation, experienced listeners rate post-instruction response much higher than pre-instruction responses. Certain directions in which the existing indicator should be developed were determined by this pilot study [7].

5. Sabbatical-year Research of Principal Investigator

During the research period summarized in this final report, Dolanský [10] spent one year in related research at the Speech Transmission Laboratory (STL), Royal Institute of Technology in Stockholm. The research findings as they relate to the research carried out at Northeastern University can be summarized as follows: an historical survey of pitch extraction methods revealed that the methods and devices used in the past fall into three main categories: (1) frequency-domain analyzers, (2) time-domain analyzers, and (3) analyzers based on other principles. Both frequency-domain and time-domain pitch extractors were represented in previous developments at STL. A study of the methods of obtaining the original signals, used to derive pitch information, lead to the considerations of (a) type of microphone (throat microphone versus more conventional type), (b) automatic volume control (to reduce the very large dynamic range ordinarily encountered in speech), (c) microphone location, (d) breath noise, (e) sound volume, and (f) related amplitude information.

The visual display methods considered to represent the intonation patterns ranged from an ordinary oscilloscope (usually unsatisfactory because of the phosphor decay characteristics) to a rotating cathode-ray tube display, storage-tube oscilloscope, carbon-powder techniques and computer-memory approach.

With respect to the use of pitch extractors for the deaf, it was found that not only could they be used effectively for a replacement of the normal auditory feedback and for self-monitoring; but that, in addition, they proved to be a welcome aid to the teachers of the deaf who sometimes found it hard to convince the students that their pronunciation is still in need of correction with respect to their intonation.

The time-varying nature of speech makes it difficult to decide how the fundamental frequency of the voice should be defined and measured. A further study of this question, based on the measurement of individual pitch periods, revealed pitch-period irregularities which tend to interfere with the methods of evaluating pitch-extractor reliability. For a statistically meaningful set of signals, it is difficult to evaluate individual extractors in isolation without the use of some additional equipment which in turn may influence the result. Therefore, using a Control Data 1700 computer, an attempt was made to produce a two-track tape which would contain a speech signal on one track and a corresponding ideal pitch-period pulse on the other, for a significant sample of continuous speech.

The research summarized in the preceding paragraphs led to the following conclusions:

(1) Pitch extractors can be significantly helpful in correcting the laryngeal frequency and intonation of deaf subjects. They are particularly helpful in (a) giving a deaf person feedback information about his pitch and intonation, (b) permitting him to self-monitor his progress with respect to pitch and intonation, and (c) aid the teacher to convince the student of the need of improvement.

(2) For optimal development of such aids and their use in the school for the deaf, a very close cooperation between the research establishment and a teacher for the deaf is essential.

(3) Perfect pitch extractors do not exist; parallel operation of several extractors can be used to reduce the error rate but the simplicity of a single extractor is probably to be preferred over the higher reliability of a multiple (parallel) extractor.

(4) The most convenient method to be used for pitch extraction is peak detection.

(5) A throat-microphone signal gives a nearly perfect pitch extraction but the subject may be uncomfortable. Signal-volume information cannot be derived from the throat microphone signal.

(6) Automatic volume control of the microphone signal should be avoided.

(7) The subject should be trained for adequate breathing habits before pitch and intonation training is started.

(8) A hand-held microphone helps the subject's concentration, while giving a more adequate signal.

(9) While some of the present-day equipment (e.g. storage oscilloscope) is adequate, it is also too bulky and expensive; simple methods should be sought.

(10) Apparently a convenient future display could be obtained by means of a small-size computer memory using an ordinary TV set for display.

More detailed information on the research activities summarized in this section will be found in refs. 10, 11, 12.

6. Research by Principal Investigator and Co-investigator on the Instantaneous Pitch-period Indicator Under VRA Grant RD-1907-S-66 (1965-66).

A study of normally hearing speakers was conducted by Dolanský, Karis, Phillips and Pronovost [8]. This study was designed to determine how normally-hearing adults could utilize the visual information displayed on the Instantaneous Pitch-period Indicator to control the pitch of their voices. Three groups of 10-12 subjects each learned to match pitch patterns under three different learning conditions. The patterns consisted of sustained high or low pitch vowels and patterns involving pitch inflections between sustained high and low pitches. Group I learned to imitate patterns which were heard only. Group II learned to imitate the same patterns which were presented aurally and visually on the IPPI, and monitored their vocal utterances both aurally and visually on the IPPI. Stimulus patterns were presented to Group III only visually on the IPPI, with no auditory component. Subjects compared their responses with the stimulus pattern on the IPPI screen. Auditory self-feedback of the vocal responses of Group III was reduced by a 95 db SPL masking noise. After a learning criterion of four correct out of five consecutive responses had been met for each of the six patterns, a practice session involving six blocks of four patterns was permitted. Subjects returned the next day for a testing session in which they matched five sets of four patterns. Groups I and III used the same manner of stimulus presentation and self-monitoring as the original learning conditions; the stimulus presentation and self-monitoring for Group II was visual only but without a masking noise. Results of the learning rate for the training session and the matching errors for the testing session were compared.

The results of the data analysis for the training sessions revealed that Group III required significantly more learning trials to meet criteria than Groups I and II. Group II, with both auditory and visual feedback, required fewer learning trials than Group I, but the difference was not statistically significant.

Error scores were computed for all subjects' matching attempts during the testing session. The error score was based on the matching of the subject's pitch inflection with the frequency transition of the stimulus. There were no significant differences in the error scores of the three groups. For all groups, error scores were higher for rising pitch inflections. The higher error scores were due predominantly to an increase in the time required for rising pitch inflections.

Analyses of the sustained frequency matching attempts, which preceded and followed the frequency transition of the pattern, revealed a greater mean frequency deviation for the higher pitch level than for the lower pitch level, in part probably due to the fact that the lower pitch corresponded to the natural pitch levels of subjects. Group I, the auditory group, had a significantly smaller frequency deviation than Groups II and III, both of whom had only visual cues during the testing session, although Group II had been trained with both auditory and visual information.

In terms of the purposes of the study, it can be concluded that normally hearing subjects, under conditions of a simulated hearing loss due to a masking noise, can learn to use visual information of increasing or decreasing frequency transitions to monitor their own pitch inflections. For the combined auditory-visual stimulus and monitoring, there was a tendency for the added visual cue to facilitate learning compared to the group which learned under auditory conditions alone. However, once the task had been learned, the groups did not differ in the error scores obtained on a test for the following day. Regardless of the manner or length of the learning process, the test revealed similar retention of the vocal encoding ability for pitch inflections. Rising pitch inflections required a longer time than falling pitch inflections, indicating that de-decreasing frequency transitions can be matched more easily than increasing frequency transitions of the same duration (150 msec). This difference in matching ability may be attributable to the fact that the falling pitch inflections involved a return to each subject's more natural pitch level from a higher pitch level.

Problems in the use of visual information for control of pitch inflections were revealed by the data. Some subjects could not reach the learning criterion for Group III, the Visual plus Noise Group, and could not be used in the study. The visual group required a longer training session, had the largest number of pattern inversions, and the greatest deviation in absolute matching of the high-frequency portion of the stimulus pattern. The study indicates that some normally-hearing individuals will experience certain difficulties in using visual information for the performance and monitoring of an auditory-vocal task.

In support and as a result of the studies summarized in this section, certain engineering developments were also pursued; these will be briefly mentioned in the following paragraphs.

While in the above-mentioned studies the fundamental frequency of the voice was represented on a linear scale, it became obvious that a logarithmic display of the frequency would be more meaningful, for at least the following two reasons: (a) the resolution on such a logarithmic scale would be more nearly the same for different categories of voices (e.g. male vs. female), (b) the intonation pattern for such different voices would be more nearly identical, except for a vertical positioning. Therefore, concurrently with the studies with subjects in which the linear display was used, a new model using the logarithmic display was also developed. A further innovation in the logarithmic-display model was the use of a box-car representation between consecutive pitch periods, in place of the originally used exponential decay; this means that the trace stays at a constant level between consecutive pitch periods and at the beginning of each period the vertical deflection is adjusted in accordance with the latest pitch period. A gradual decay to some fairly low quiescent level no longer occurs.

In order to generate certain stimulus patterns (which the subjects were required to imitate) in an easier, automatic, and more consistent way, a visual-pattern generator was constructed. With the help of the latter, it is possible to generate certain patterns, e.g. the ones in which the frequency suddenly increases or decreases in a step, artifically by recording a filtered square-wave signal having the desired frequencies and feeding the latter directly to the pitch extraction and display equipment. Thus, while based on an artificial rather than an actual speech signal, exactly the same pattern could be presented to all subjects and, when only the visual presentation is used, the pattern is indistinguishable from one generated by an actual speech signal. Further details about the engineering developments outlined in the last two paragraphs can be found in ref. 9.

In connection with these engineering developments, the additional question of the fastest response of the subjects to a stimulus pattern containing a sudden step in frequency was studied under two different kinds of stimulus presentation: (a) simultaneous development of the stimulus and the response pattern on the screen, (b) the presentation of the subject's response after the entire stimulus pattern has been presented. Disregarding the data obtained for the experimenter himself and using measurements obtained for six subjects, the delay in the response to a sudden increase in frequency ranged from .26 to .59 sec., while the maximum slope of this increase ranged from 3.43 to 8.85 sec.$^{-1}$; for previously stored stimulus patterns, these slopes ranged from 1.87 to 11.6 sec^{-1}.

B. Results Obtained by Other Researchers

Historical factors in the development of visual displays of speech information have been treated by Pickett [29] and Pronovost [33]. These reviews indicate a hundred years of interest in visual displays of speech, with the majority of technical developments occurring more recently. Technical developments progressed more rapidly than the acceptance of the aids by teachers of the deaf. Except for some Scandinavian countries, few of the aids have found their way into the daily functioning of teachers of the deaf.

Recently a survey of Visual Information Display Systems was prepared for the National Aeronautics and Space Administration [46]. The report includes descriptions of display systems and components; it is pointed out that "the human being remains the least understood part of the display systems".* The report summarizes research in progress and suggest areas of needed research. "One of the questions that has not been adequately answered is the relative value of various modes of presentation: visual, auditory and tactile."*

The pitch indicators which have been developed are those described by Coyne [4], Plant [30], Anderson [1], Tjernlund [40] and Stark [38]. Work with deaf children on pitch level and intonation is described in these papers and by Mártony [24]. These studies involved only a few subjects in each, and tended to be descriptions of a variety of individual approaches in which visual feedback concerning pitch level and intonation was provided as one aspect of a training program. All authors observed improvements in the pitch usage of their subjects and interpreted the results as encouraging. The results were not analyzed to determine the specific contribution made by the visual feedback of pitch information in the training program.

Woodward [44,45] has developed materials and procedures for teaching intonation to the deaf, based on linguistic principles. Although no data are presented, empirical impressions indicate success with deaf children. The materials and procedures are appropriate for incorporation into programs using IPPI.

The use of "A Self Instructional Device for Conditioning Accurate Prosody" in second-language learning was reported by Buiten and Lane [3]. A Speech Auto-Instructional Device called SAID is based on principles of programmed learning. The machine presents tape-recorded pattern sentences, compares the tape signals and the students' imitative responses for pitch, loudness and tempo by means of parameter extractors and a computer-comparator, and displays the students' errors as variations on a zero-center meter. A student's imitative response is presented three times on the meter, first for pitch, second for loudness, and third for tempo. For pitch, a light indicates that the subject should imitate the "pitch contour" of a pattern.

*[46, p.9].

During the imitation, the meter swings to the right if the response is too high in pitch, and to the left if too low in pitch. The computer causes the pattern to be replayed for successive imitations until an imitation is within acceptable limits. The device then presents the task of loudness imitation. Results with one subject showed that pitch was imitated in the fewest learning trials. Tempo was easier to match than loudness but more difficult than pitch.

The application of reinforcement principles in the experimental manipulation of fundamental voice frequency has been reported by Holbrook and Meader [16], Roll [36] and Holbrook [15]. A device was constructed to indicate when a subject produced pre-determined pitch levels successfully. The training program was based on reinforcement principles. Through this procedure, subjects were able to learn to read aloud in new pitch levels. The researchers intend to apply this approach to changing the pitch levels of deaf speakers who use pitch levels which are too high or too low for effective voice usage.

Results of training programs dealing with attributes of voice and speech other than pitch have been reported by Weaver [41], Kopp and Kopp [18], Pronovost [32, 34], Searson [37], House [17], Kringlebotn [19], Pickett [28], Risberg [35] and Stark [38]. These studies varied from reports of informal and clinical training to experimental learning studies. Results were interpreted as promising, although numbers of subjects were usually small, and further research was suggested. As with the pitch studies, it is difficult to determine the specific contribution of the visual feedback to the speech changes observed.

Some authors have raised questions and urged caution in the use of visual aids for speech. Liberman et al. [20] point to the difficulties in visual perception of the rapidly changing displays of acoustic features, making speech spectrograms difficult to read. They point out that perhaps visual representation of articulatory muscle contractions may be the most meaningul for the deaf. Stewart [39] points out that the human ear, with the aid of phonetic symbols for phonemes and supra-segmental phonemens, may be a more useful means for describing the features of deaf children's speech to teachers of the deaf in speech training programs. He does, however, indicate that length and pitch are particularly hard to assess aurally.

Marimont [23] has suggested that basic research on speech is necessary if research on visual speech trainers is to be successful. She suggests that "a program to develop suitable visual speech trainers ... be planned in the following steps:

1. A survey of the state of the art in machine decoding and processing of speech, to ascertain whether the decoder and manipulator required are presently available...

2. A survey of the state of the art in narrow bandwidth speech transmission systems, to see what information reduction has been accomplished without affecting intelligibility, and thus to identify critical features.
3. Mathematical analysis of the logic of the simplest and most successful systems studied for an understanding and possible simplification of the logic used.

The need for further research in speech perception and measurement was stressed also in a panel discussion at a conference at the Air Force Cambridge Research Laboratories (Lindgren [22]).

C. Conclusions

The recent technical developments of speech-analyzer aids for the deaf, and the results of preliminary studies, indicate that the speech-analyzer aids hold promise as equipment for visual feedback and self-monitory systems in speech training programs for the deaf, and that research should be continued with greater attention to experimental design and usefulness for teachers of the deaf.

IV METHOD

The methodology of this two-year study emphasized the interaction of several professional disciplines represented on the staff, including a principal investigator who is an electrical engineer, a co-investigator with experience in speech science, speech pathology and education of the deaf, a full-time teacher of the deaf, graduate electrical engineers, and a speech and hearing scientist with experience in research design and statistical analysis. Involvement of all members of the research team occurred simultaneously throughout the project.

The major phases of the project were engineering design and modification, development and modification of teaching programs, and testing of specific teaching programs with deaf children and adults. These phases were overlapping. Initial programs were devised to fit the capabilities of the equipment at a particular time. However, trial programs with the equipment tended to result in modifications of both equipment and program, with engineering modifications related to program needs as circuit designs were refined, and programs being redesigned to meet the needs of deaf subjects as indicated by data and observations during pilot projects. Thus, program design and refinements were not independent of engineering refinements or of data obtained in experimental studies. The focus of the various phases of the study was to arrive at a feasible unit of equipment, accompanied by a program for its use in teaching intonation patterns to deaf subjects.

The following paragraphs describe the major phases of the study which are detailed in subsequent sections of this report.

The first aspect involved the construction of a revised model of the pitch-extractor and display equipment (described in the next section as Model II), for use in the experiments conducted in the Speech Communications Laboratory with deaf adults and deaf children.

A pilot training program was conducted with nine deaf adults, using the IPPI oscilloscope screen. The subjects attempted to match the pitch patterns displayed. The following signals were used in consecutive sessions, occurring once or twice weekly, for periods up to several months for some subjects: (1) sustained tone patterns involving constant pitch, (2) sustained tone patterns with a step change between two frequencies, either up or down, (3) pitch patterns derived from three-word phrases of conversational speech, (4) extreme rising and falling inflections using one-word expressions. Toward the end of the training program, the subjects were given only delayed feedback, subsequent to their own matching attempts.

The research teacher of the deaf tabulated the subjects' successful responses to each stimulus in each session. The data were interpreted by inspection, since the high degree of variation from subject to subject in number of trials and sessions precluded any quantitative analysis. The research teacher of the deaf also kept anecdotal notes on each subject's progress and his reaction to the equipment and to the training program. These empirical observations were then summarized for the group of subjects.

Tape recordings of each subject's speaking of thirteen test phrases were made before and after the training program. The phrases were not practiced during the training. The effectiveness of the training program was evaluated by listener judgments of randomized paired presentations of pre-training and post-training recordings of each phrase for each subject. Twenty-five teachers of the deaf were used as listener-judges. Thus, the effectiveness of the training program for deaf adults using the IPPI was evaluated by listener judgments and two types of empirical observations.

An experimental training program was conducted using fourteen deaf children, ages 9 to 15, who were pupils at the Horace Mann School for the Deaf. The experimental program involved eighteen testing and training sessions over a nine-week period. The training program was designed as a result of the experience with the deaf adult experiment, combined with experiences of two of the current investigators with the Voice Visualizer Project [32]. The program involved a series of tasks in rhythm and intonation, using nonsense syllables, words and phrases. Testing sessions were held at the beginning of the program and after each four sessions of training. The total program was completed by eight subjects; for various reasons, six discontinued the program before the end of the nine weeks. Instantaneous visual feedback from the IPPI was provided during all testing and training sessions.

Tape recordings were made of all testing sessions. Listening tapes were developed utilizing samples of each test task for each test period. A panel of six listeners compared utterances of the same test items for Test 1 and Test 2, Test 2 and Test 3, Test 3 and Test 5. These listener judgments provided the basis for evaluating the effectiveness of the training program with the IPPI. The research teacher of the deaf also prepared case summaries and anecdotal notes on each child's responses to the program and to the equipment.

The fourth aspect of the project was the engineering development of a portable model of the IPPI. Engineering refinements, including both electronic and mechanical design, were carried on concurrently with the adults' and children's experiments. Some of the refinements resulted from problems which developed during the experimental programs; others were new developments suggested by the experience with the adults and children. Additional features included new electronic circuits for processing the pitch signal, the addition of a headset for the subject, a separate teacher's microphone, a set of lights for vocal intensity display, signal lights for instructing a subject when to phonate, and five alternative modes of triggering the oscilloscope sweep and erasing the pattern. All features of the new model were incorporated within the cabinet of the Hewlett-Packard storage oscilloscope by remodeling or replacing the plug-in units. The final model is portable and can be placed on a cart for use in classrooms for the deaf.

This final model of the equipment, and the program recommended for future research with deaf, is therefore based on increased technical knowledge of the engineers in equipment design for the intended purposes, and increased knowledge of the features to be included in a training program based on results of specific trial techniques and the needs exhibited by the deaf subjects.

V. EXPERIMENT I - DEAF ADULTS

A. Development of Pitch Indicator - Model II

1. System Objectives

The objective in constructing this pitch indicator was to obtain a complete working system so that a study with deaf adults could be carried out, while further improvements for subsequent studies with children (see Ch. VI) and for a final portable unit (see Ch. VII) were being developed. In the design of this system the following principles, elements and features were to be adopted.

(a) existing amplifiers and pitch-detecting circuits
(b) transistorized pulse-to-analog circuit
(c) light-indication and triggering circuits, in order to minimize random triggering
(d) limit generators for pattern matching
(e) provision to offset patterns of male and female voices by a fixed amount, for easier pattern matching between different habitual pitch levels
(f) automation of display and taping controls, in order to free the teacher of the deaf for other duties

2. System Outline

The operation of the system is best described with the help of the system block diagram (Fig. 4) and certain pertinent waveforms (Fig. 5).

A Crown tape recorder is started and runs during the time in which stimuli and responses are being generated. To begin a specific stimulus-response sequence, the Ampex recorder is started. This signal is recorded on the Crown tape recorder, and also drives a sequencer circuit. During the duration of the 10kHz signal, and for about 1 sec thereafter, a Schmitt trigger circuit is energized. The output of this circuit is used to turn on a green light, which indicates that the stimulus will be displayed momentarily. When the Schmitt trigger circuit turns off, a one-shot multivibrator (MV 1) is triggered, and remains in the exicted state for approximately 3 1/2 sec. During this time, Relay R1 is activated so that the recorded stimulus may trigger the oscilloscope sweep. Also, a limit generator develops a variable magnitude square wave which goes to the mixer. When the stimulus is reproduced by the Ampex recorder, it is amplified by the Crown recorder and the amplified signal triggers the oscilloscope through Relay 1. It also is processed by the IPPI and P-A circuits, giving an analog output proportional to the logarithm of the frequency of the stimulus. This analog signal is mixed with the square wave of the limit generator and offset by the male-female switch to give a double-line pattern on the Tektronix 564 oscilloscope. The amplified stimulus signal also drives the intensity-control circuit which turns up the intensity of the writing beam during voiced portions of the stimulus and of the response. When MV1 goes off, it triggers MV 2, which causes Relay 2 to open, thus stopping the Ampex recorder. The gate is also held on, allowing Relay 1 to remain closed so that the response can trigger the oscilloscope. A red light is on when MV 2 is in the excited state. This is used to inform the subject that he can respond. If additional responses are desired, using the same stimulus, a trigger switch may be closed, so that the voice signal can trigger the oscilloscope.

a. Pitch Detector.

The fundamental frequency of the voice signal is detected with the help of envelope detection. An instantaneous pitch-period indicator [5] is used to develop one pulse per period. This signal is used to drive the P-A converter shown in Fig. 6. This circuit represents a modification of a circuit developed previously under a related

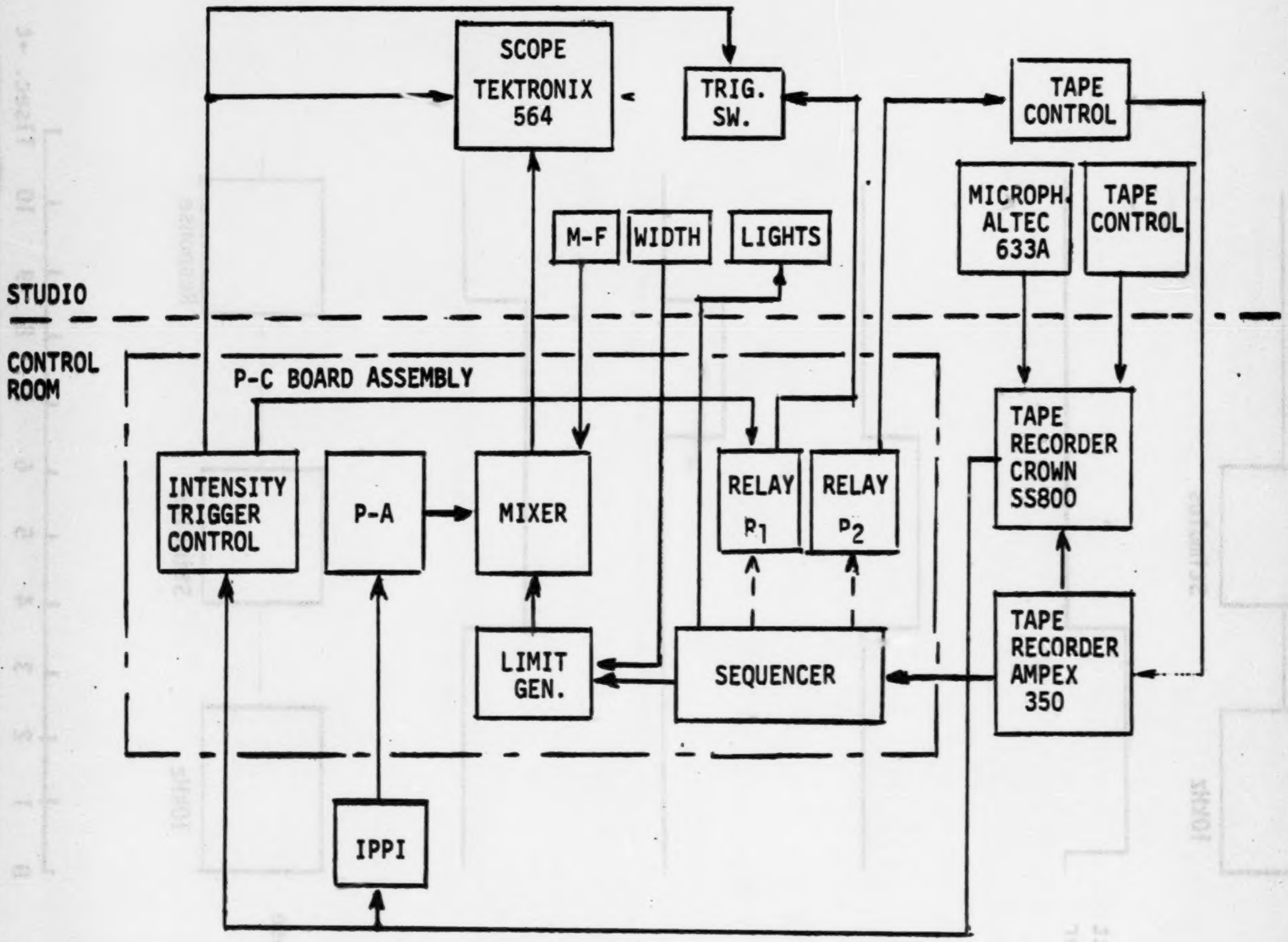

SCOPE
TEKTRONIX 564
TRIG. SW.
TAPE CONTROL
M-F
WIDTH
LIGHTS
MICROPH. ALTEC 633A
TAPE CONTROL
STUDIO
CONTROL ROOM
P-C BOARD ASSEMBLY
INTENSITY TRIGGER CONTROL
P-A
MIXER
RELAY P1
RELAY P2
TAPE RECORDER CROWN SS800
LIMIT GEN.
SEQUENCER
TAPE RECORDER AMPEX 350
IPPI

Fig. 4. Block Diagram of Display and Control System.

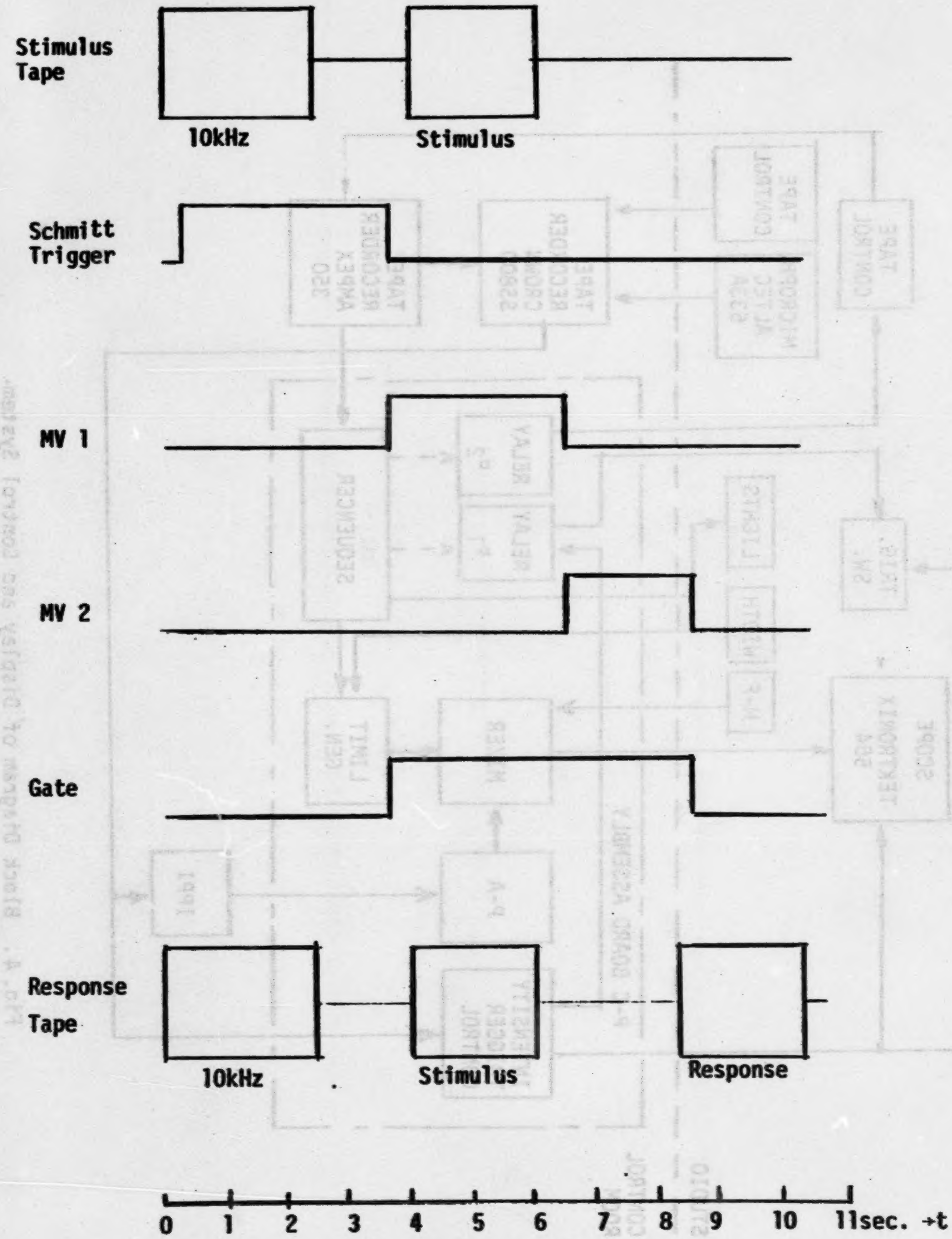
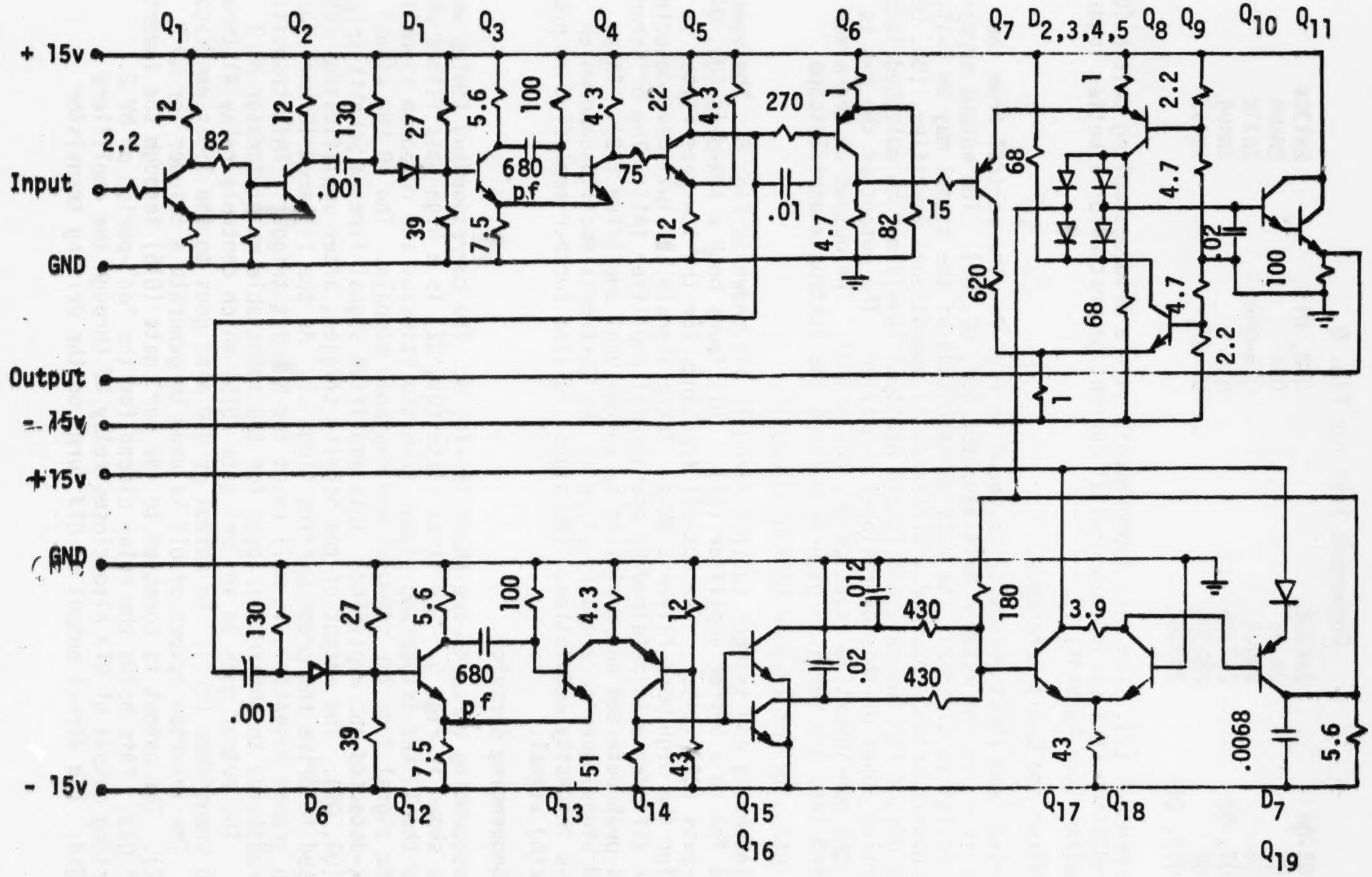

Stimulus Tape
10kHz
Stimulus
Schmitt Trigger
MV 1
MV 2
Gate
Response Tape
10kHz
Stimulus
Response
0
1
2
3
4
5
6
7
8
9
10
11sec. →t

Fig. 5. Waveforms indicating timing of stimulus, sequencing, and response signals.


Q1
Q2
D1
Q3
Q4
Q5
Q6
Q7
D2,3,4,5
Q8
Q9
Q10
Q11
+ 15v
Input
GND
Output
- 15v
+15v
GND
- 15v
2.2
12
82
12
.001
130
27
39
5.6
7.5
680 pf
100
4.3
75
22
4.3
12
270
.01
1
4.7
82
15
620
68
1
68
2.2
4.7
4.7
2.2
.02
100
1
130
.001
27
39
5.6
7.5
680 pf
100
4.3
51
12
43
.02
.012
430
430
180
3.9
43
.0068
5.6
D6
Q12
Q13
Q14
Q15
Q16
Q17
Q18
D7
Q19

Resistances in kOhm, capacitances in µf unless otherwise specified.

Fig. 6. Pulse-to-analog converter (P-A).

Component list for Fig. 6

Q1-Q4	2N1304	Q12, Q13	2N1304
Q5	2N338	Q14	2N404
Q6	2N404	Q15-Q18	2N338
Q7, Q8	2N1305	Q19	2N404
Q9	2N1306	D1-D7	1N457
Q10, Q11	2N338		

research project [9]. The main improvements were a bridge-sampling switch (D2-D5) and the addition of a second exponential current generator for a better logarithmic approximation (see Appendix I).

b. Mixer and Limit Generator

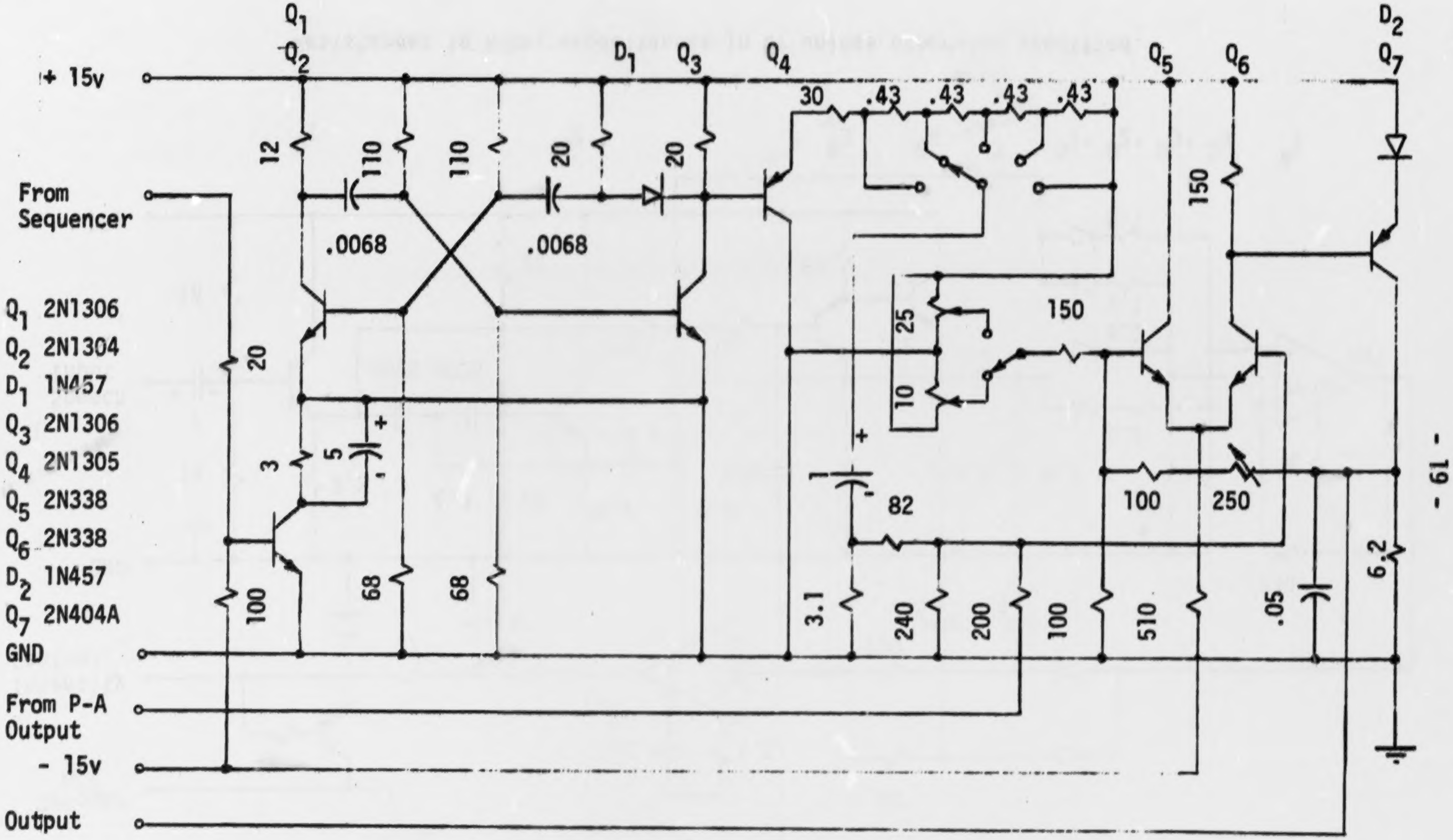
The mixer and limit generator is shown in Fig. 7. The control from the sequencer turns on the astable multivibrator (Q1, Q2, Q3). The output appears across a resistive divider. The desired magnitude of the signal may be switched into the non-inverting input of a differential operational amplifier, (Q5, Q6, Q7). The offset for the male and female habitual levels may be switched into the inverting input of this operational amplifier. The output of the P-A is fed into the non-inverting input of Q5, Q6, and Q7. The output of the mixer is then fed into the vertical plug-in unit of the Tektronix oscilloscope.

c. Intensity and Trigger Control Circuits.

The intensity and trigger control circuits are shown in Fig. 8. The speech signal is fed to a buffer amplifier (Q1). This feeds both a low-pass (Q3, Q4) and high-pass (Q2) filter. The cut-off frequency for the low-pass filter is 800 Hz, for the high-pass filter 2.5kHz. These signals are full-wave detected and their difference is obtained by operational amplifier (A1). The difference signal is peak-detected and amplified by operational amplifier (A2). This amplified signal goes to a modification in the Tektronix oscilloscope which allows d-c intensity modulation. The signal is also further amplified to produce a triggering signal.

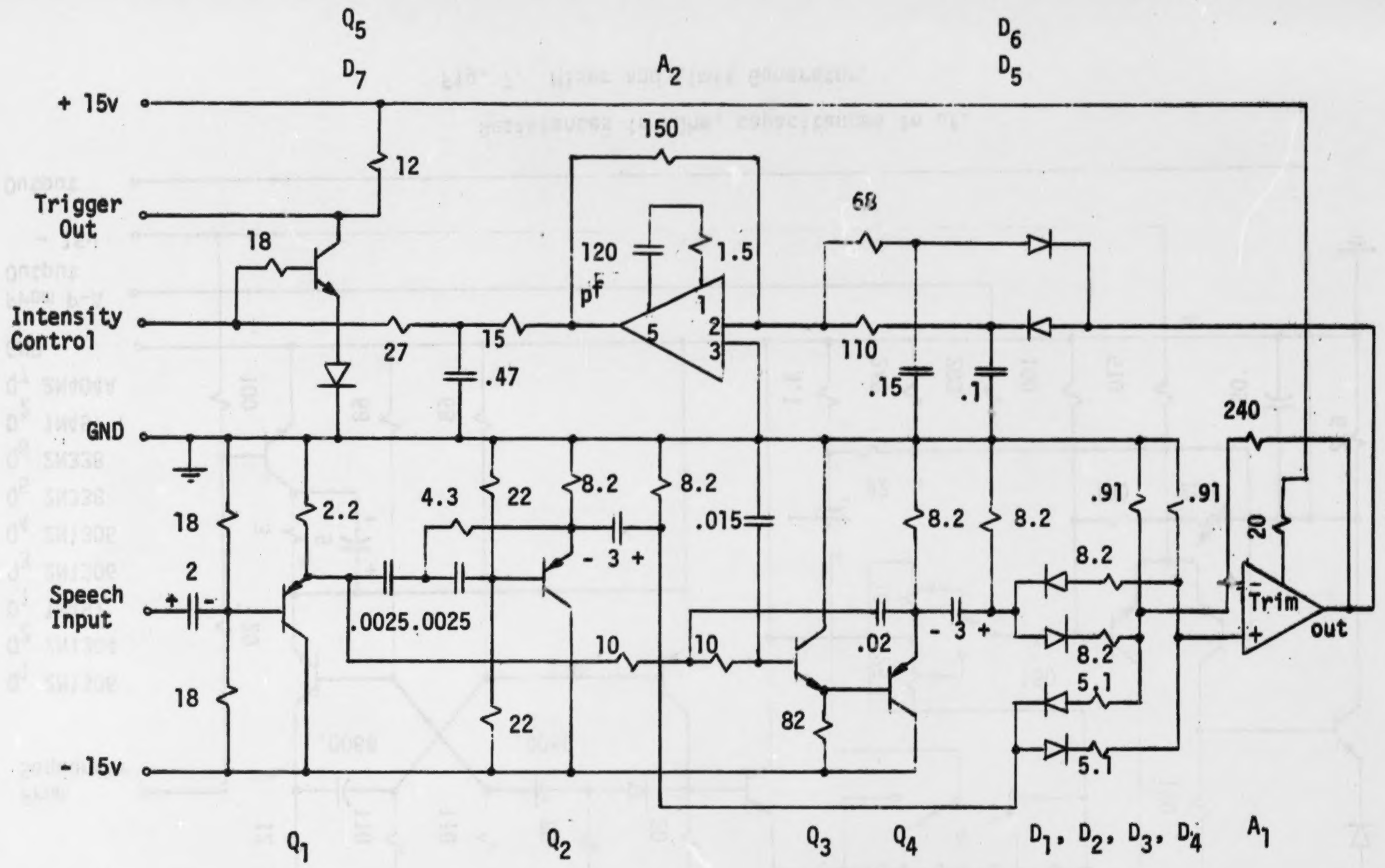
d. Sequencing Circuits

The sequencing circuits are shown in Fig. 9. The corresponding timing waveforms are shown in Fig. 5. The first state (Q1, Q2) is a high-pass filter which separates the 10 kHz triggering signal from the stimulus and response signals. The 10 kHz signal from the stimulus and response signals. The 10 kHz signal is then peak-detected and amplified. This amplified signal fires a Schmitt trigger circuit (Q4, Q5). The output of the Schmitt trigger, after amplification (Q8, Q9) is used to drive the green warning light L1. As the filtered 10 kHz signal decays to ground potential, it will reset the Schmitt trigger. This transition is differentiated to obtain a trigger for the monostable multivibrator MV 1 (Q6, Q7). The output goes to an "or" gate (Q15) which controls relay R1 through a driving transistor (Q16). An output of Q10 also goes to the limit-generator control. The inverted output of Q10 is used to generate a trigger for MV 2 (Q11, Q12). The output is conected to the "or" gate (Q15) through the inverting output of Q13. This holds the relay closed for the "on"-period of MV 2. The inverting output of Q13 also closes relay R2 through the amplifiers Q17 and Q18. The direct output of Q13 turns on the driving transistor


+ 15v
From Sequencer
Q1 2N1306
Q2 2N1304
D1 1N457
Q3 2N1306
Q4 2N1305
Q5 2N338
Q6 2N338
D2 1N457
Q7 2N404A
GND
From P-A Output
- 15v
Output
Q1
Q2
D1
Q3
Q4
Q5
Q6
D2
Q7
12
110
110
20
20
.0068
.0068
20
3
5
100
68
68
30
.43
.43
.43
.43
25
10
150
150
1
82
3.1
240
200
100
510
100
250
.05
6.2

Resistances in kOhm, capacitances in μf.

Fig. 7. Mixer and Limit Generator.


Q5
D7
A2
D6
D5
+ 15v
Trigger Out
Intensity Control
GND
Speech Input
- 15v
12
18
27
15
.47
150
120 pF
1.5
1
2
3
5
68
110
.15
.1
240
20
Trim
out
-
+
18
2
18
2.2
4.3
22
8.2
8.2
.0025
.0025
- 3 +
10
10
22
.015
.02
82
8.2
8.2
- 3 +
.91
.91
8.2
8.2
5.1
5.1
Q1
Q2
Q3
Q4
D1, D2, D3, D4
A1

Resistances in kOhm, capacitances in µf unless otherwise specified.

Fig. 8. Intensity - Trigger Control.

Component list for Fig. 8

Q1	2N1305
Q2	2N404A
Q3	2N1304
Q4	2N404A
Q5	2N1306
D1-D7	IN100
A1	Philbrick PP55AU
A2	Amelco 809CE

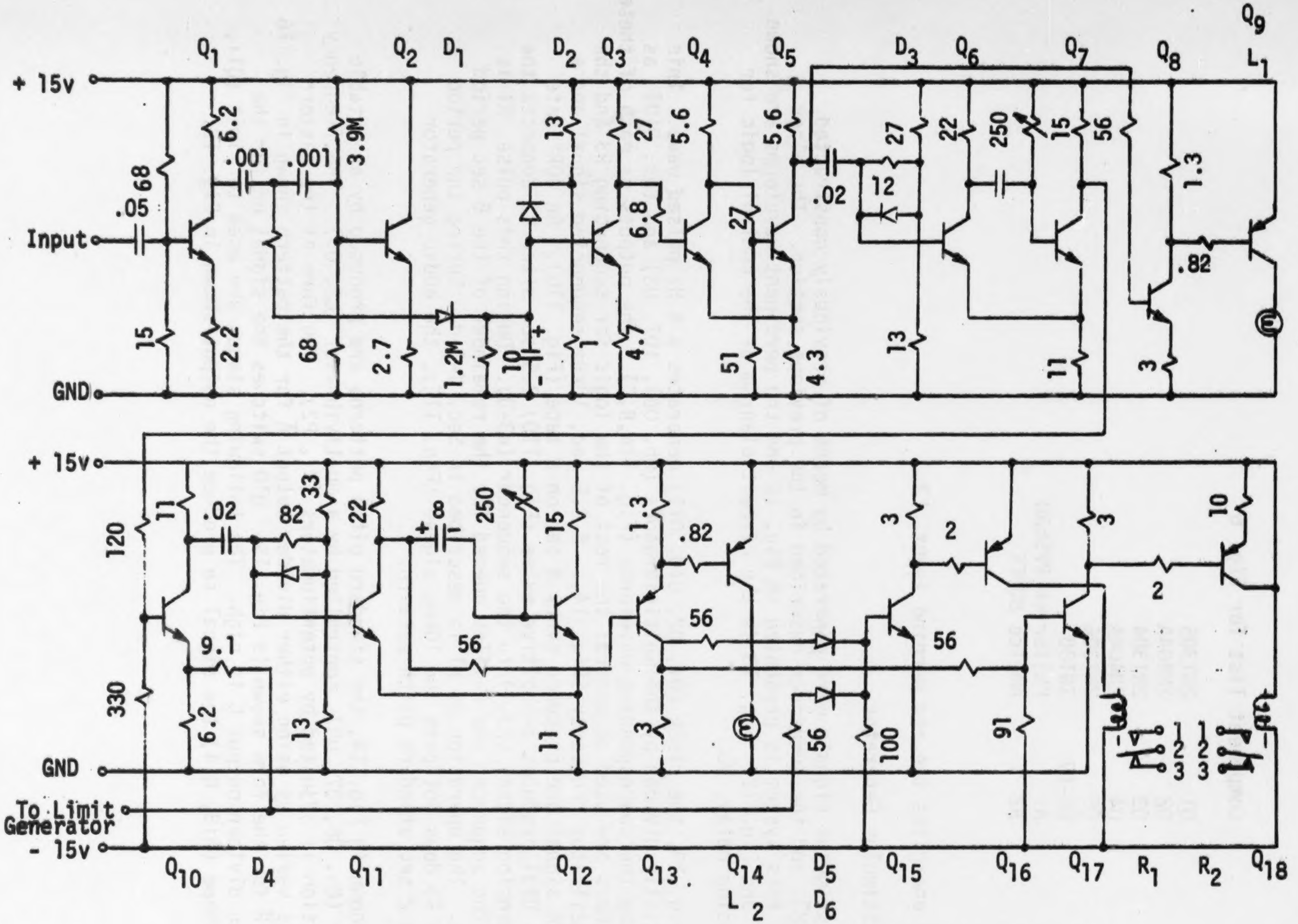
Q14, which energizes the red warning light, L2.

e. Stimulus Generator.

The stimulus signals were generated by means of previously constructed circuits [8], and the sequencer described in the previous section. The block diagram of this system is presented in Fig. 10 and the pertinent waveforms are shown in Fig. 11 and Fig. 12. Fig. 13 is the circuit diagram of the control logic for the sequencing relay, R3.

In Fig. 13, the clock (Q1, Q2, Q10, Q11) generates a 4 Hz pulsed wave. This is sequentially divided by the multivibrators (Q5, Q6), (Q7, Q8) and (Q9, Q10), as reflected by the corresponding waveforms (Fig. 11A,B,C). The outputs of each of these three dividers are used to control the rest of the logic for sequencing R3 and the astable oscillator frequency (Fig. 14). A 2.5 sec, 10kHz sequencing signal and a 2 sec audio signal are produced every 8 sec on a tape (Fig. 11G). An "OR" gate (D11, D12, D13) produces a positive pulse (Fig. 11D) 2.5 sec after R3 connects the 10kHz sequencing signal (R3-1) to the sequencer (R3-3). During this pulse, R1 is opened by the sequencer and remains opened for the remainder of the 8 sec period (Fig. 11F). The operation of R1 is described in Sec. V-A-d. During the period when relay R3 does not pass the 10kHz signal (Fig. 11E), the audio generator produces a 2 sec standard pitch pattern.

As shown in Fig. 14, the standard pitch patterns are produced by an astable oscillator (Q5, Q6, Q7, Q8), controlled by a multivibrator (Q2, Q3). The frequency of oscillation is adjusted by potentiometers (P1, P2). The form of the pattern produced is varied by using either divider output $\overline{A}$ for the pattern shown in Fig. 16 or output $\overline{B}$ for the form shown in Fig. 15. Q10 switches the signal on for the period when divider output C is high. The following stages are used to limit (Q11, Q12) and shape (Q13, Q14) the signal to produce the output shown in Fig. 12.


+ 15v
Input
GND
+ 15v
GND
To Limit Generator
- 15v
Q_1
Q_2
D_1
D_2
Q_3
Q_4
Q_5
D_3
Q_6
Q_7
Q_8
Q_9
L_1
Q_{10}
D_4
Q_{11}
Q_{12}
Q_{13}
Q_{14}
L_2
D_5
D_6
Q_{15}
Q_{16}
Q_{17}
R_1
R_2
Q_{18}
.05
68
15
6.2
2.2
.001
.001
68
3.9M
2.7
1.2M
10
13
1
27
6.8
4.7
5.6
27
51
5.6
4.3
.02
27
12
13
22
250
15
56
11
1.3
.82
3
120
330
11
.02
82
33
9.1
6.2
13
22
8
250
56
15
11
1.3
.82
56
3
56
100
3
2
56
91
3
2
10
1 2 3
1 2 3

Resistances in kOhm capacitances in µf unless otherwise specified.

Fig. 9. Sequencing circuit

Component list for Fig. 9

Q1-Q3	2N1306
Q4,Q5	2N1304
Q6,Q7	2N1306
Q8	2N1305
Q9	2N351
Q10	2N1304
Q11,Q12	2N1306
Q13	2N1305
Q14	2N351
Q15	2N1304
Q16	2N404A
Q17	2N1304
Q18	2N404A
D1-D6	IN457
L1,L2	Chicago 304
R1,R2	W.E. 275B

B. Subjects

The subjects were nine deaf adults between the ages of 20 and 63. Volunteer subjects were recruited from members of the Oral Deaf Adults Section of the Alexander Graham Bell Association for the Deaf, residing in Eastern Massachusetts, and from deaf adults enrolled in an adult education program conducted by the Speech and Hearing Foundation of Massachusetts. Although twelve subjects began the program, only nine completed the program with sufficient amount of data in order to be used in the listener analysis portion of the study.

A personal data and history questionnaire was completed for all subjects. Audiometric examinations were conducted by the audiologist of the Northeastern University Speech and Hearing Clinic. The questionnaire data and audiograms for each subject are included in Appendix A.

Subjects had an average hearing loss of 80 db (ISO) or more in both ears at 500, 1000, and 2000 Hz. Five subjects were congenitally deaf; the others acquired deafness at age five or under. Seven subjects attended a normal high school upon completion of their grammar school education; two subjects attended college. Subjects were engaged in the following occupations: dental technician, laboratory technician, cashier, factory worker, keypunch operation, typist, accountant. Subjects socialized with both deaf and hearing populations, though preferences differed. All but two subjects used the oral method in communicating and had good articulation and lipreading abilities; the others used the combined method, relying heavily on signs and finger spelling.

As an indication of the deaf adult subjects' visual perceptual ability, each subject was given the test of perception of imbedded figures reported by Witkin [31]. The test is scored by the total time required to perceive the imbedded figures. The total times for each subject, and the subject's rank within the pitch-indicator study, are given in the case study information in Appendix A. All subjects had scores within one standard deviation of the means reported by Witkin for a population of 102 college students. The variation between subjects was less than that reported by Witkin for his population, so that it can be assumed that the subject's visual perception, as measured by an imbedded figures test, was within normal limits.

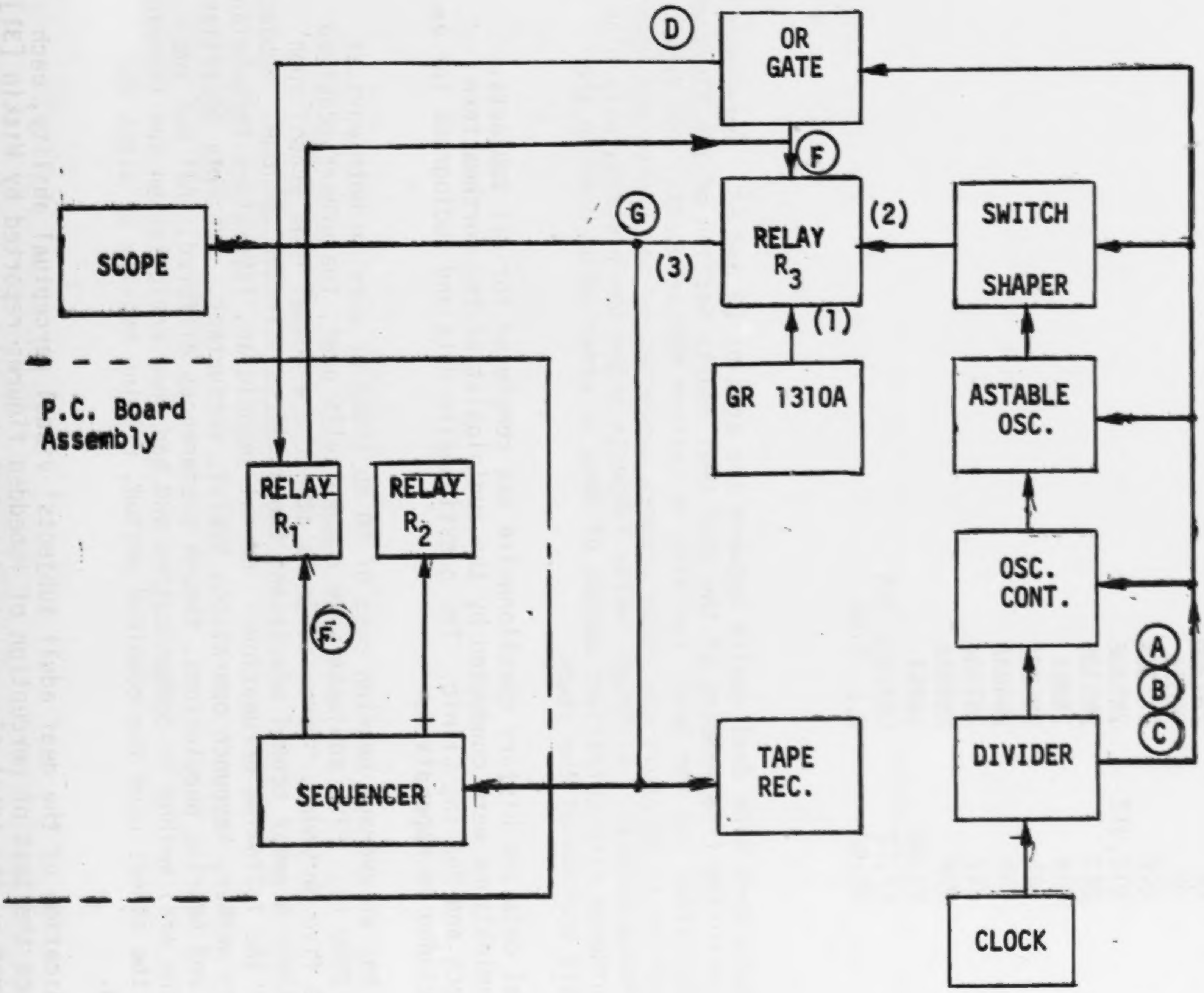

D
OR GATE
F
G
RELAY R$_3$
(2)
(3)
(1)
SWITCH SHAPER
SCOPE
GR 1310A
ASTABLE OSC.
P.C. Board Assembly
RELAY R$_1$
RELAY R$_2$
F.
OSC. CONT.
A
B
C
SEQUENCER
TAPE REC.
DIVIDER
CLOCK

Fig. 10. Block diagram of stimulus tape generator for study of adult deaf subjects.

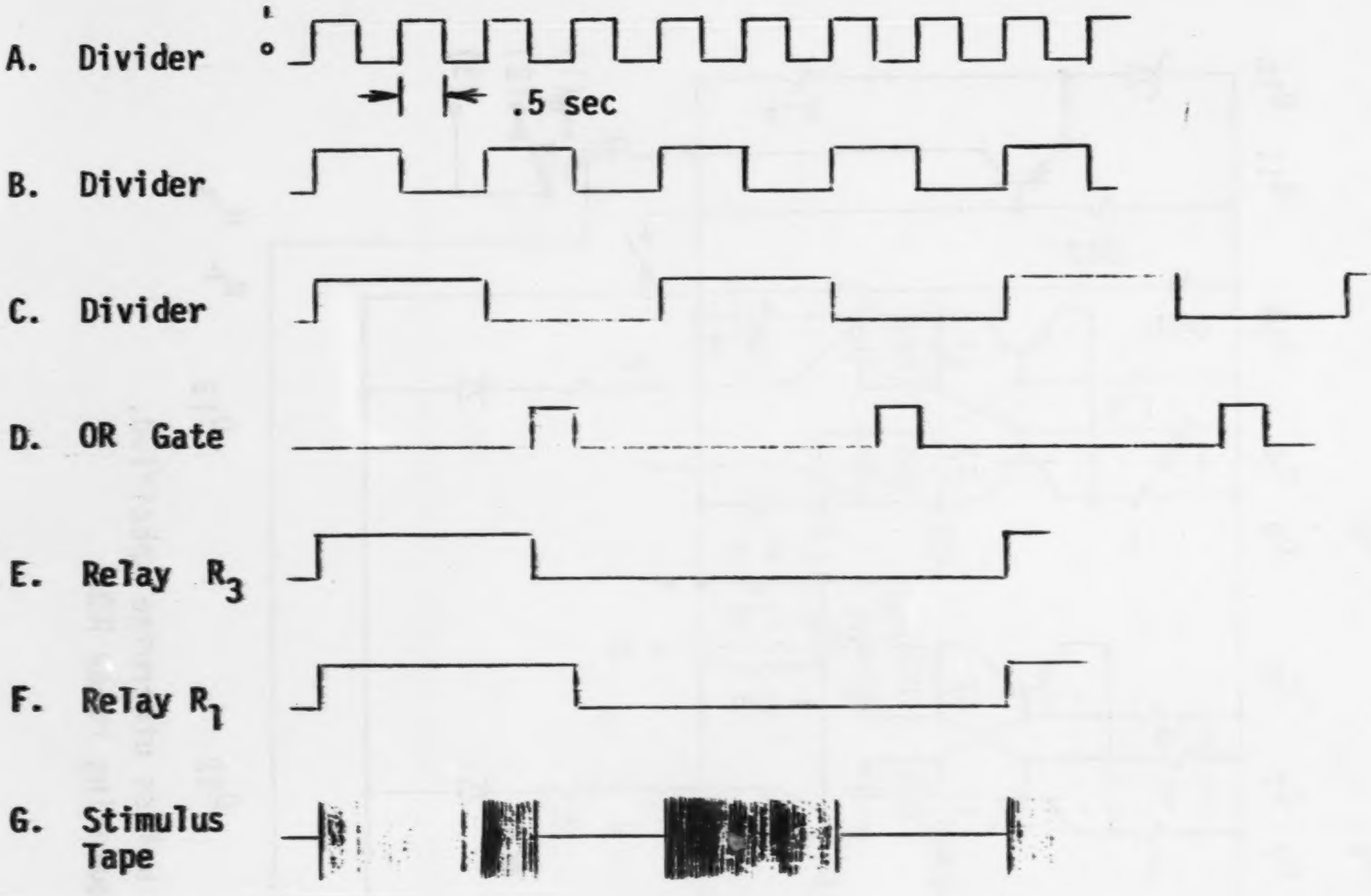


Fig. 11. Waveforms for Stimulus Generator.

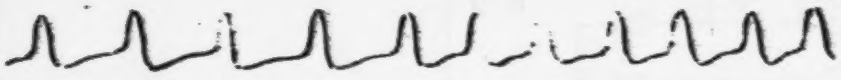


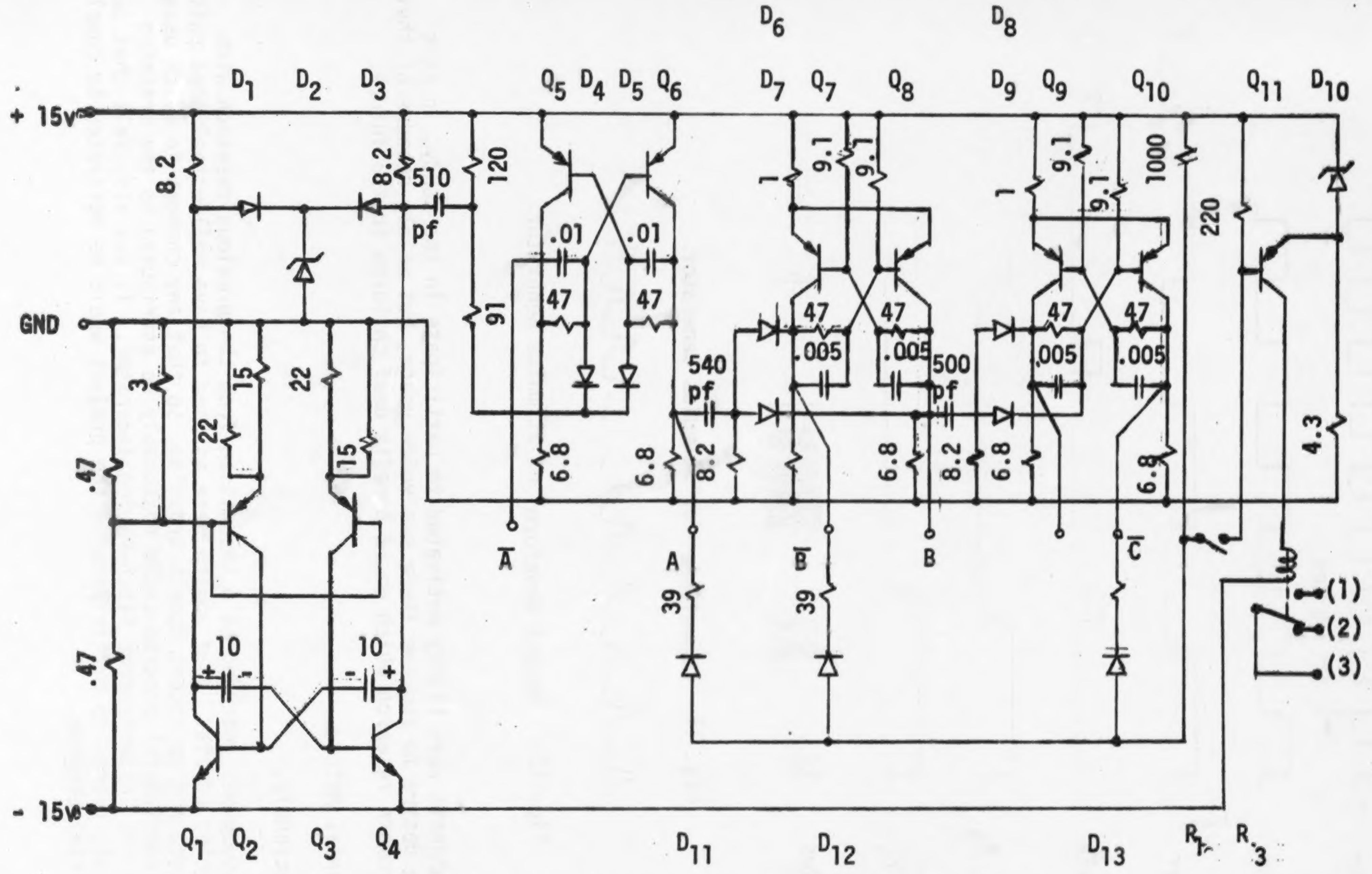
Fig. 12. Output Waveform of Stimulus Generator.

All subjects were highly motivated to participate in the study, in part because of a desire to improve their own voice usage, but mainly because of their desire to promote research which would benefit deaf children in the future.

C. Experimental Method.

1. Rationale.

This study was intended as a transition from the previous research with normally hearing adults. Deaf adults were assumed to have well-established patterns of pitch usage, and no recent speech training, so that any changes in pitch usage during the experimental program could reasonably be attributed to the training program with the Instantaneous Pitch-Period Indicator. It was also felt that deaf adults who volunteered to participate in the project would be motivated to complete the experimental program.


+ 15v
GND
- 15v
D_1
D_2
D_3
D_4
D_5
D_6
D_7
D_8
D_9
D_{10}
D_{11}
D_{12}
D_{13}
Q_1
Q_2
Q_3
Q_4
Q_5
Q_6
Q_7
Q_8
Q_9
Q_{10}
Q_{11}
8.2
8.2
510 pf
120
91
3
15
22
22
15
.47
.47
10
10
.01
.01
47
47
6.8
6.8
540 pf
8.2
1
9.1
9.1
47
47
.005
.005
500 pf
6.8
8.2
6.8
1
9.1
9.1
1000
47
47
.005
.005
6.8
220
4.3
$\overline{A}$
A
$\overline{B}$
B
$\overline{C}$
39
39
(1)
(2)
(3)
R_1
R_3

Resistances in kOhm, capacitances in μf unless otherwise specified.

Fig. 13. Control logic for sequencing relay R3.

Component list for Fig. 13

Q1	2N1302
Q2,Q3	2N404A
Q4	2N1302
Q5-Q10	2N1303
Q11	2N1305
D1	IN457
D2	IN705A
D3-D9	IN457
D10	IN712
D11-D13	IN457

It was recognized that replication of the same experimental design as that used with normally hearing adults would not be feasible with a deaf adult population. It was assumed that deaf adults would require longer periods of time to learn the required vocal imitative tasks. While it was desired that deaf adults undertake the same vocal pitch imitative tasks as the normally hearing population, it was also desired that intonation patterns of speech be included in the training.

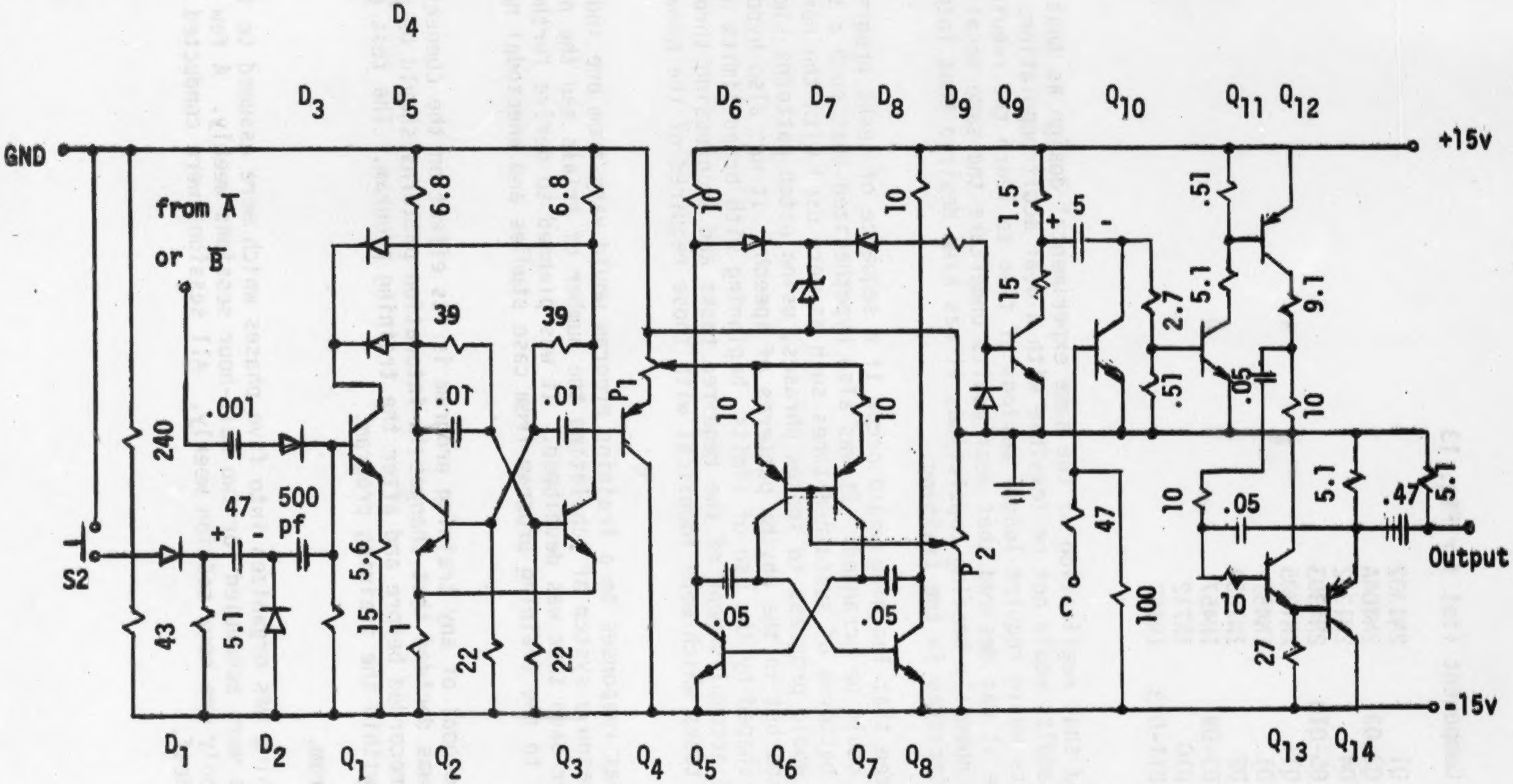
It was hypothesized that learning would occur if a sequence of tasks progressing from easy to difficult could be arranged. It was also hypothesized that such a sequence would begin with pitch patterns of sustained tones such as were used with the normally hearing population and would progress to spoken phrases, using pitch patterns similar to those for sustained tones but in the rhythm patterns of speech. It was also hypothesized that behavior could be shaped by the use of limits, beginning with broad limits which would permit successful accomplishment of the required tasks and progressing through reduction of limits to tasks which were identical with those required of the normally hearing adults.

It was assumed that responses to a training program would vary from one individual to another; for this reason a system of tabulating the number of trials and the number of successful responses for each task was developed. It was planned to derive further data on individual responses to the training program from case studies and anectodal notes about each session.

Since the ultimate goal of any training program is its effect on the connected speech of subjects, it was decided that changes in intonation patterns should be measured in spoken phrases tape recorded before and after the training program. The test phrase would not be practiced within the training program.

2. Training Program.

A program of training was organized into five phases which were assumed to increase in difficulty. Subjects were scheduled for two half-hour sessions weekly. A few subjects' schedules would permit only one hour session weekly. All sessions were conducted by a trained teacher of the deaf.


GND
from $\overline{A}$
or $\overline{B}$
S2
240
43
.001
47
+
-
500 pf
5.1
D1
D2
D3
D4
D5
Q1
Q2
Q3
Q4
5.6
15
1
6.8
6.8
39
39
.01
.01
22
22
P1
D6
D7
D8
D9
Q5
Q6
Q7
Q8
Q9
10
10
10
10
10
.05
.05
P2
1.5
15
5
+
-
Q10
C
47
100
2.7
.51
5.1
.51
.05
9.1
10
10
Q11
Q12
Q13
Q14
10
.05
27
5.1
.47
5.1
+15v
-15v
Output

Resistances in kOhm, capacitances in µf unless otherwise specified.

Fig. 14. Variable frequency generator and wave shaper.

Component list for Fig. 14

Q1-Q3	2N1302
Q4	2N1303
Q5	2N1302
Q6,Q7	2N404A
Q8	2N1302
Q9	2N1304
Q10	2N1306
Q11	2N1304
Q12	2N1303
Q13	2N1306
Q14	2N1305
D1-D6	IN457
D7	IN705A
D8	IN457
D9	IN34

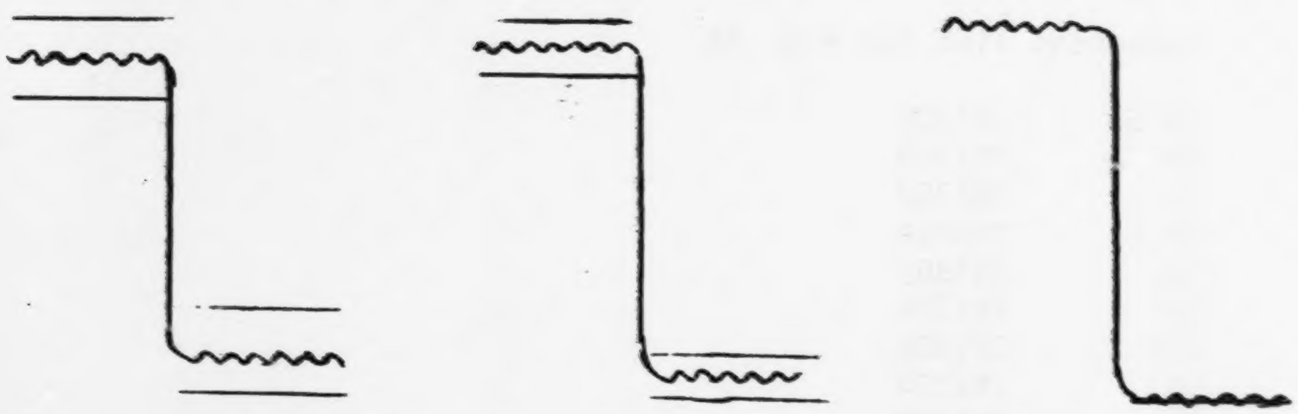
Phase I of the program dealt with the production of single pitch levels and of upward and downward changes between two sustained pitch levels. There were six standard pitch patterns used as training models in this phase of the program: Low, Low to Medium, Low to High, High, High to Medium, Medium to Low; the frequencies for each of these levels are listed in Table I. The model patterns were prerecorded on tape.

Table I. Model Pitch Levels and Corresponding Frequencies.

Pitch Level	Male	Female
Low	130Hz	220Hz
Medium	155	261
High	185	311

Each model pattern could be presented as a double trace, bracketing the desired pitch level between two horizontal lines (see e.g. Fig. 15). The spacing between the lines, which could be varied from no space to a space of about two semi-tones, was controlled by the teacher. A successful trial was one for which the pitch of the subject fell between the lines.

While the model pattern was stored on the oscilloscope screen, the subject phonated */a/* and attempted to match the model. For the first presentation the two lines were set at the widest separation. If the subject achieved success in four out of five trials, the space between the two lines was narrowed for the next trial, until a single line was matched. Each of the six patterns in Phase I was presented in the same manner. If a successful match between the response and stimulus patterns was achieved, or when new patterns could no longer be seen clearly because of their number, the screen was cleared by manually depressing an erasure switch.



Two-tone limit One-tone limit Matching single-line tone

Fig.15. Illustration of narrowing limits. Downward shift; straight lines show limits presented as stimulus pattern. Curved lines show subject producing a pattern within the limits.

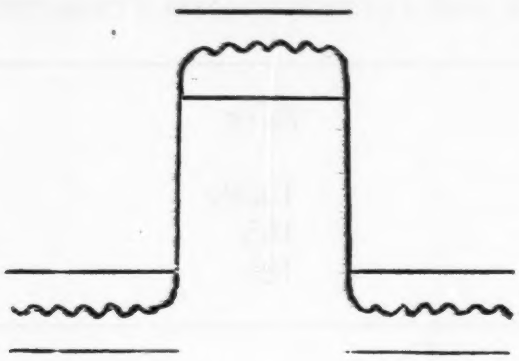


Fig.16. Illustration of two-level intonation pattern for Phase 2, using limits.

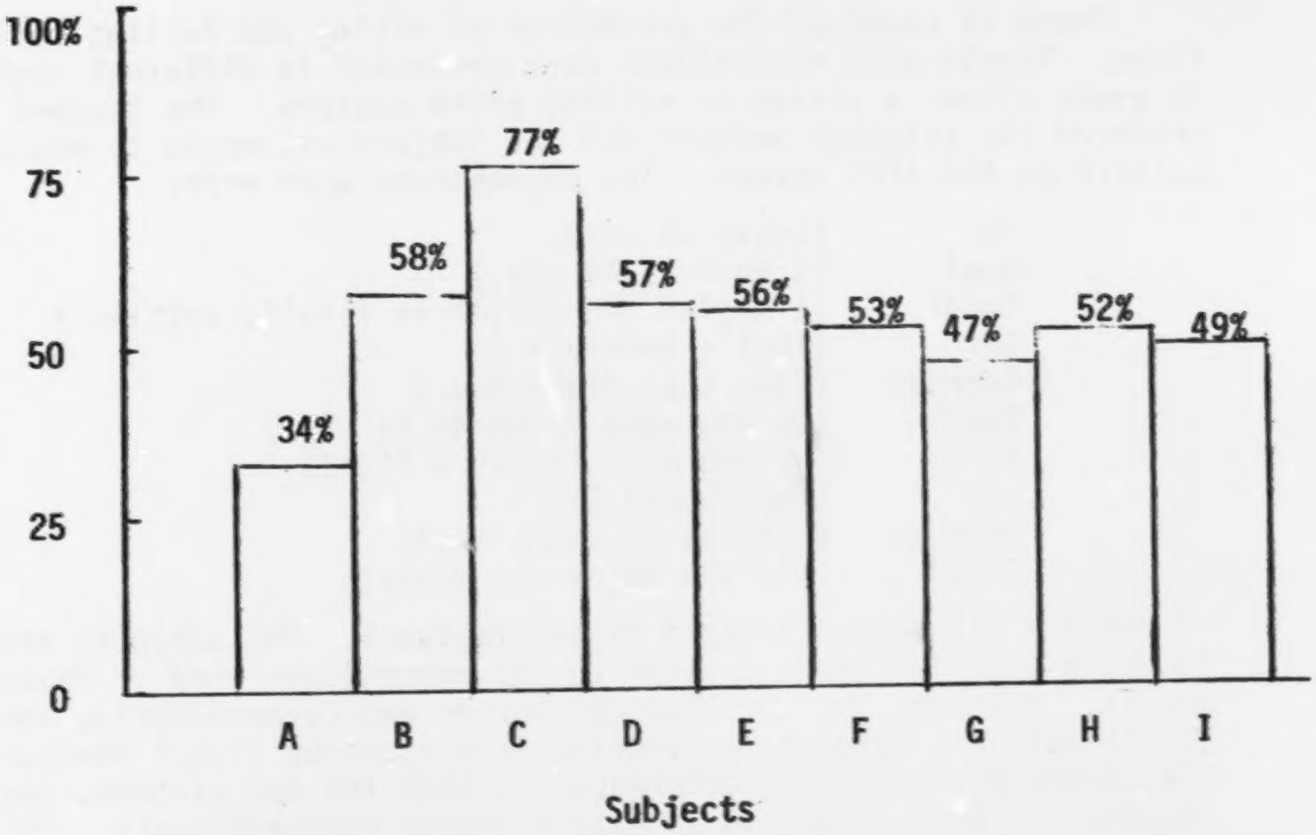


Fig. 17. Percentage of responses in which listeners judged the post-test better than the pre-test, for each subject.

Phase II involved the production of two-level patterns of three sections which resemble the intonation patterns of conversational speech. Two standard pitch patterns were displayed: Low to Medium to Low, and Medium to High to Medium (Fig. 16). The training procedure was the same as that for Phase I.

Phase III was concerned with the production of intonation patterns using three-word phrases of conversational speech. The subjects attempted to imitate pitch changes associated with expressions which used two-level intonation patterns similar to those practiced in Phase II. The teacher made a tape-recording of the expressions so that the pitch patterns to be matched were the same for each subject. The model pitch pattern was presented as a single trace. In the latter part of Phase III, three-word phrases associated with different intonation patterns were introduced. Phrases practiced during Phase III were:

How are you?
Good morning.
What's your name?
What day is it?
Where are you?
I like you.
Move over.
Get out of here.
Go quickly.
I mean it.

Phase IV required the production of rising and falling inflections. Single-word expressions were presented in different contexts to evoke either a rising or falling pitch pattern. The teacher then produced the stimulus pattern and the subject attempted to match the pattern on the IPPI screen. The expressions used were:

Go!	(Leave at once.)
Now!	(I mean right now.)
Good!	(I'm glad the matter is finally settled.)
Oh!	(That's terrible.)
George!	(Stop that right now.)
Now?	(Do you want me to do it now?)
Fire?	(Do you mean there's a fire?)
Go?	(Why should I?)
George?	(Will he be there too?)
Good?	(Did you enjoy the movie?)

Phase V introduced delayed visual feedback. The subjects attempted to match pitch patterns similar to the expressions used in Phases III and IV. However, the oscilloscope screen was covered during the subject's matching attempt, preventing instantaneous visual monitoring. The screen was uncovered afterwards so that the two patterns could be compared by the subject on a delayed visual feedback basis. Phrases used for practice were:

I thought so.
He kicked me.
What time is it?
That's my book.
Who called me?
Good evening.
Talk softly.
Don't do that.
Dress nicely.
It's your turn.

Fool!	(You're a fool.)
Well!	(I didn't expect to find you here.)
Red!	(My brother bought a red car.)
Hurry!	(Hurry, or we'll be late.)
No!	(Don't ever go there again.)
Fool?	(Why did you call me a fool?)
Well?	(Tell me quickly. I must know.)
Red?	(Did you say this car is red?)
Hurry?	(Why should I? There's plenty of time.)
No?	(Are you sure you won't go with me?)

3. Procedures for recording and analyzing data

a. Analysis of training program evaluations

During the training program, the research teacher of the deaf tabulated the number of attempts a subject made to match a stimulus pattern and the number of successful matching attempts. Tabulations for one subject are presented in Appendix C. The number of attempts per stimulus varied greatly from subject to subject so that no comparative quantitative analysis could be made. A trend analysis is presented in the results section based on empirical inspection of the tabulations of all subjects.

b. Clinical impressions of research teacher

The research teacher of the deaf made anecdotal notes of her observations of the subjects' responses during the training program. These observations are summarized in Sec. V-D.

c. Tape recordings and listener analyses

During the introductory session with each subject, a tape recording was made of the subject's speaking of thirteen phrases. The phrases (sentences) were designed to be representative of conversational speech and were similar to commonly used expressions, (see Appendix B). Each sentence was presented on a flash card and the subject was asked to say it as he would in conversation. These phrases were also recorded in the last session with each subject. None of the test phrases were used in the training program.

A listener tape was prepared for comparing each subject's use of pitch in speaking the test phrases before and after training. The phrases were recorded with the pre-test phrase occurring before or after the post-test phrase in random order. The randomization was arranged over the total of 117 phrases spoken by the nine subjects.

The group of twenty-five listeners was composed of eight teachers of the deaf who had at least two years' experience following completion of graduate training,eight graduate students in the education of the deaf who had completed a year of student teaching, and nine graduate students in speech pathology who had completed at least one year of clinical practice and graduate study. The following instructions were given to the listeners:

> You will hear tape recordings of nine deaf adults speaking the thirteen phrases on the sheet you have been given. You will hear each phrase twice, separated by a tone of 1000 Hz. You will hear all the phrases spoken by one speaker in the order listed on your sheet. You will then hear the next speaker's phrases, and so on through nine speakers.
>
> The phrases were spoken before and after a training program with the Instantaneous Pitch-Period Indicator. Please indicate which of the two expressions of a phrase has the more natural pitch pattern in your judgment. The order of the recordings has been randomized so that a subject's second expression of a phrase may be either his first or second tape recording. Mark your judgment on the IBM card, marking column A if you judge the first expression heard to have the more natural pitch pattern, and column B if you judge the second expression to have the more natural pitch pattern.

You will hear two sample items on the test tape. Do not mark your card for these test items. Begin to mark your card when you hear "Speaker A, Phrase 1."

Data Analysis was carried out by means of a computer evaluation of listeners' judgments, as recorded on the IBM cards. The percentage of listener judgments for which the post-test phrase had a more natural pitch pattern than for the pre-test utterance of the phrase was computed for each phrase spoken by each speaker. The Chi square technique was used to determine whether the judged differences represented improvement of pitch usage between the pre- and post-test recordings.

D. Results

1.Analysis of training program evaluations

Tabulations of the number of stimulus matching attempts and the number of successful matchings of subject I-C are shown in Appendix B. In reviewing these data and similar data for all other subjects, it became apparent that there was a high degree of variability among subjects. This variability existed in the number of stimulus matching attempts from task to task, required to achieve some degree of success. In addition, some subjects were unsuccessful in certain tasks but achieved a degree of success in subsequent tasks assumed to be more difficult. The great variability between and within subjects precluded any quantitative analysis of the data. Inspection of the data did reveal that some subjects tended to have difficulty with the sustained phonation tasks, but were able to achieve a degree of success on imitative tasks using phrases of speech (Phases III and IV of the training programs). The data indicate that drill with sustained phonations of the type employed in this study is not a necessary prerequisite to training with spoken phrases.

The total number of hours of training time for each adult subject is shown in Table II. This table also reflects the variability in the amount of time that the subjects were able to spend with the IPPI. Some of the variability in hours of training resulted from equipment malfunctions which prevented the use of the IPPI in particular practice sessions.

Table II. Amount of Training Time with IPPI for Adult Subjects

Subject	Hours of Training
I-A	17
I-B	11
I-C	17
I-D	6
I-E	9
I-F	17
I-G	14
I-H	13
I-I	14

2. Clinical impressions of research teacher

The research teacher of the deaf made the tabulations illustrated in Appendix B for all subjects and prepared the case studies presented in Appendix A. The research teacher's general observations of the adults' responses to the training program may be summarized as follows:

(a) All subjects became aware that they could change their pitch.

(b) Four subjects who complained of voice strain at the start of the program felt less strain as the sessions progressed.

(c) Three of the six subjects who wore hearing aids, frequently preferred to perform the tasks with their hearing aids turned off.

(d) All subjects attempted initially to raise their pitch by increasing their vocal intensity; five of them learned to raise their pitch without significantly changing vocal intensity.

(e) All subjects used the seven model pitch patterns as guides for phonating phrase patterns and single word patterns.

(f) All subjects improved their intonation patterns after practicing the rhythm pattern for each expression.

(g) All subjects improved their production of inflections when the task words and phrases were placed in an emotional context.

(h) Five subjects responded more accurately with the aid of kinesthetic cues.

(i) Three subjects achieved better pitch changes while attempting to sing and indicated that they felt more relaxed while singing than while talking.

(j) All but two subjects experienced more difficulty in producing a rising inflection then in producing a falling inflection.

(k) Five subjects did as well with delayed visual feedback as they had done with immediate feedback.

(l) One subject recited fifteen new expressions while receiving visual feedback only after each production. He recited twelve of the phrases correctly.

(m) All subjects preferred Phases III-V (speech tasks) to Phases I and II.

3. Listener analyses of tape recordings

The data from the listeners' judgments of thirteen pre-test and post-test phrases spoken by nine deaf adults are shown in Table III. For each

Table. III. Number of Listeners Selecting the Post-test Phrase as Sounding More Natural than the Pre-test Phrase.

	Phrase Number													
Subject	1	2	3	4	5	6	7	8	9	10	11	12	13	Total Number of Listeners
A	**24	14	16	8	6	10	10	6	12	*4	*5	8	*2	28
B	**26	15	15	7	12	10	**25	14	27	18	10	9	18	27
C	No response			**24	16	**23	**23	**26	19	**23	11	**22	21	27
D	20	*5	9	19	21	**17	**24	9	19	12	16	18	12	27
E	13	11	**22	8	16	**19	16	15	19	11	9	15	17	26
F	12	12	*4	10	**21	16	18	8	16	15	16	**21	12	26
G	**25	8	*1	*4	**21	10	**21	16	11	7	16	*4	18	26
H	8	14	*4	6	6	**21	13	**23	18	13	**23	10	17	26
I	17	13	16	10	**21	7	*5	11	12	13	12	15	15	26

*Significant difference - Regression
**Significant difference - Improvement
For Chi Square Table - See Appendix

subject and phrase, each entry in the table represents the number of listeners judging the post-test response as "sounding more natural" than the pre-test response. The right hand column shows the total number of listeners for each subject. In order to determine the statistical significance of these judgments, the appropriate Chi-Square technique was applied (see Appendix D). There were twenty statistical significant post-test phrases judged as having "a more natural pitch pattern", while ten pre-test responses were judged statistically significantly "more natural in pitch pattern". Neither the pre-test nor the post-test responses of the remaining 84 phrases were selected by a sufficiently large number of listeners to be statistically significant. For the entire group of subjects, the range was from 34% preference to 77% preference for post-test response, with most of the speakers falling near the 50% mark (see Fig.17). It should be noted that subject A was cited by the research teacher of the deaf as showing improvement; however, the listeners' judgments indicated the opposite. It was also noted by the research teacher that subject A's pre-vocal and post-vocal quality was quite different. The teacher reported that the subject was quite nervous during the post-test and appeared to be overly motivated, resulting in an unnatural vocal quality. This clinical observation was supported, and is reflected in Fig.17, where subject A's post-test phrases were selected by 34% of the listeners, who were responding to "the most natural pitch pattern" of the two responses. In other words, a large amount of the post-test phrases chosen as less natural pitch pattern were spoken by a speaker who, according to the research teacher, had better intonation patterns than most of the other subjects. Consequently the listeners may have been responding, in part, to a difference in vocal pitch level and quality rather than pitch patterns.

From the data of Table III, and Fig.17, it appears that, in terms of listener preference and pre-test and post-test phrases, there was little improvement resulting from practice with pitch-shift tasks. There did, however, appear to be a slight trend in the direction of improvement.

E. Discussion and Conclusions

The original intent of the study with deaf adults involved an attempted modification of the sustained phonation-learning tasks of the normally-hearing-adult study (Dolanský [8]), the addition of decreasing limits in the stimulus patterns as a behavior-shaping technique for the deaf population; the inclusion of training with spoken expressions and phrases, and the evaluation of the effectiveness of the training by means of three devices, including a comparison of pre-test and post-test tape recordings of each subject's speech.

Several problems were encountered as the training program progressed. The subjects experienced varying degrees of difficulty and success with the sustained pitch-pattern tasks. Instability of equipment responses for for several utterances of various subjects resulted in some sessions being shortened or cancelled. Subjects also varied in their attendance at scheduled sessions. However, corrections were made in circuit design and the equipment functioned with increasing stability. Nine subjects completed all phases of the originally planned training program.

Although the tabulations of stimulus-matching attempts and successes did not yield data that could be analyzed quantitatively, the clinical impressions of the research teacher of the deaf were that all subjects improved in certain tasks involving spoken expressions and short phrases using the IPPI for visual monitoring of pitch usage. The improvements noted by the research teacher were not evident in the listeners' judgments of pre-test and post-test utterances of phrases by the subjects. It is probable that there was an unrealistic expectation of improvement on phrases that were never practiced during a relatively small number of training hours with the IPPI, with half the training program devoted to non-linguistic vocalizations.

In interpreting the results of their experience with this training program for adults, the researchers focused on the implications for a training program to be used with children. It was evident that the training program should focus on visual monitoring of speech rather than of sustained phonations. The researchers had also noted that many adults had difficulty with the rhythm patterns of the spoken phrases being used for teaching intonation. Two of the research staff had noted similar difficulties with rhythm patterns of speech in a study with the Voice Visualizer for improving articulatory proficiency of deaf children (Pronovost [32]). Therefore, it was concluded that the IPPI training program to be used with children should begin with practice on rhythm patterns, prior to practice with intonation patterns. This conclusion, coupled with other empirical observations, would be used as the basis for designing a sequential series of rhythm and intonation tasks which could be assumed to increase in difficulty for deaf children.

The variability among subjects in the adult study suggested that deaf children might function at different individual levels for the various tasks of the training program. Therefore, the imitative pitch tasks were arranged into a test battery to be tape-recorded prior to training so that deaf children would only need to have training practice on those tasks which they could not perform.

Experience with the deaf adults also indicated that motivation decreased as the same tasks were performed for a long period of time. A similar observation had been made with the deaf children in the Voice Visualizer study [32]. Therefore, it was concluded that a wide variety of practice materials should be provided and that time should also permit spontaneous initiation of new learning activities by both child and teacher.

The tape recorded pre-tests and post-tests of the adult study had spanned a space of three to six months, so there was only one measure of possible change in intonation usage. With the simplification of the learning tasks and a test battery more related to the tasks being taught, it was concluded that the test battery should be administered every two weeks during the training program to measure any short-term gains and also to determine whether the sequence of the series of tasks involved increasing difficulty.

Thus, the prime contribution of the data analyses of the use of IPPI for teaching intonation patterns to deaf adults was to suggest teaching procedures to be used experimentally in a program for deaf children. In addition, it is important to call attention to the highly significant improvement made by subject I-C during the adult programs.

VI. EXPERIMENT II - DEAF CHILDREN

A. Engineering Developments.

1. Objectives.

Engineering efforts in connection with this experiment were concerned with the following three main objectives:

(a) to incorporate into the existing equipment (see Fig. 4) an integrated-circuit pitch extractor, and to accomplish this with a minimum of time delay.

(b) to obtain a two-microphone input in place of the one-microphone input used previously.

(c) to remove certain confusions experienced in the usage of the equipment when the subject responded to the indicating lights either too quickly or with considerable hesitation.

In implementing the objectives, it was decided that, with respect to objective (c), the use of sequencing circuits for this experiment should be eliminated.*

With respect to objective (a), an integrated-circuit pitch detector (Fig. 18) was developed and incorporated into the equipment shown in Fig. 4. This produced an entirely solid-state intonation-display setup. In this form, the equipment is portable; it was demonstrated at the conference on Speech Analyzing Aids for the Deaf [29].

2. Circuit Description.

The operation of the newly developed circuit is best understood with the help of Fig. 18. This preamplifier-pitch detector circuit includes two microphone preamplifiers (A1), in order to implement objective (b) as stated above. In addition, another input, e.g. from a tape recorder, can be fed into the terminal "AUX. INPUT". Any of the three above-mentioned input signals pass through the amplifier-mixer stage A2 and a 4 kHz low-pass filter A3. This filter is included to reduce the occurrence of erroneous indications for the speech sounds [z], [ʒ]; these speech sounds have a considerable high-frequency content. The filter output is fed into the cascaded pitch-period indicating stages (A4, A5), which operate in a manner similar to the stages of the Instantaneous Pitch-period Indicator of Dolanský [5]. The output of A5 is peak-detected and differentiated in A6 so that a sharp pulse is obtained for every pitch period of voiced sounds. This output pulse serves as the input signal to the pulse-analog circuit of the display and control system (P-A, Fig. 4). However, in contrast to the setup of Fig. 4, the microphone signals are now fed into the pitch indicator circuit directly rather than via a tape recorder, and the input to the intensity trigger control is obtained from the mixer output (A2, Fig. 18)

Component list for Fig. 18.

D1-D3	IN100
A1-A6	Amelco 809CE

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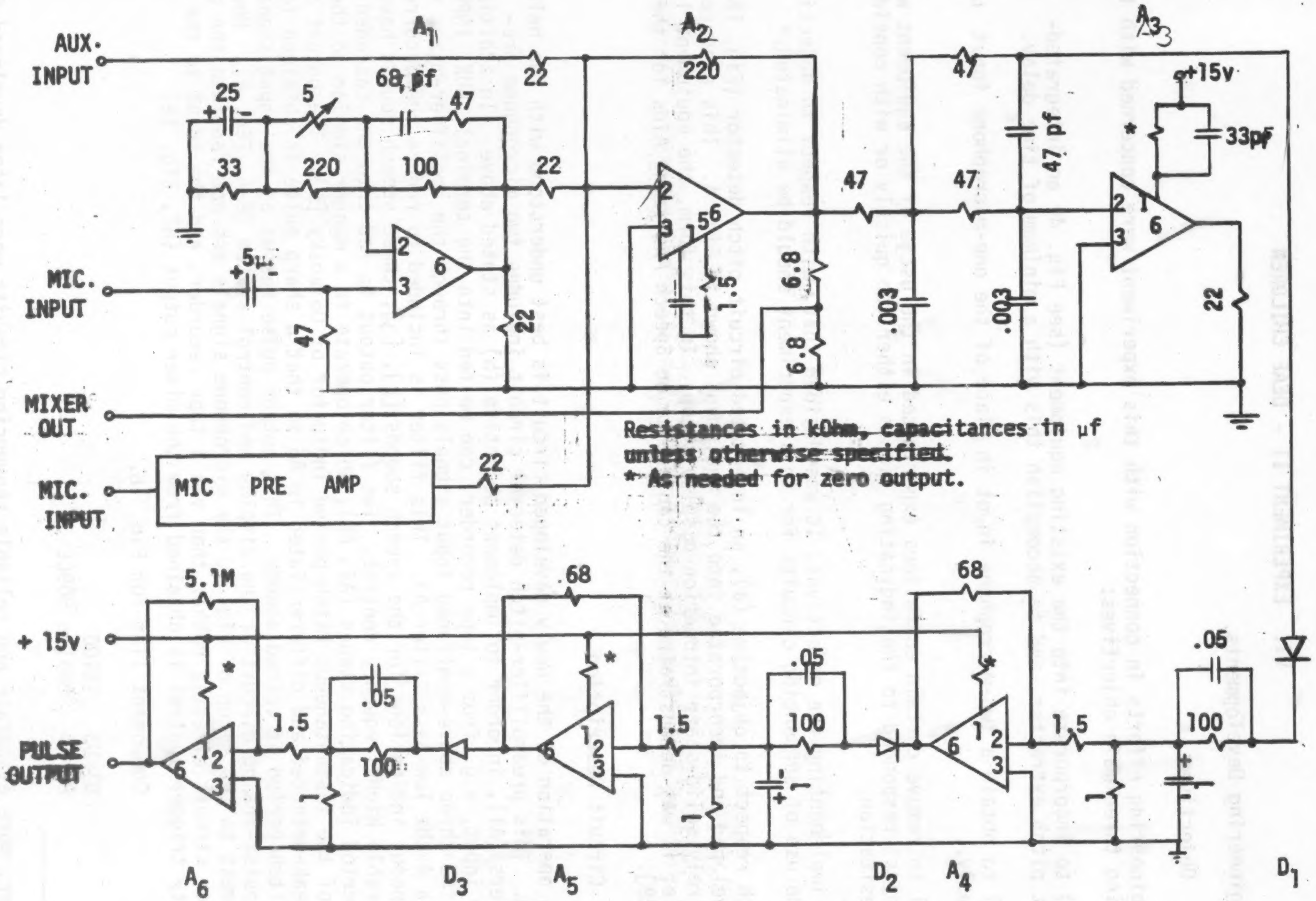
* However, more elaborate and reliable sequencing circuits were later developed for the IPPI-AID addition of the equipment (see Chap. VII).


AUX. INPUT
MIC. INPUT
MIXER OUT
MIC. INPUT
MIC PRE AMP
+ 15v
PULSE OUTPUT
A1
A2
A3
A4
A5
A6
D1
D2
D3
25
5
68 pf
47
33
220
100
22
5μ
47
22
22
220
1.5
6.8
6.8
47
47
.003
.003
47 pf
+15v
33pF
22
5.1M
68
68
1.5
.05
100
1.5
.05
100
1.5
.05
100
*

Resistances in kOhm, capacitances in μf unless otherwise specified.

* As needed for zero output.

(Component list on p. 39)

Fig. 18. Preamplifier - Pitch Detector

B. Subjects

The subjects were thirteen deaf children between the ages of eight and fifteen, who were enrolled in the Horace Mann School for the Deaf in Boston. Audiograms and description of communicative behavior of each child are presented in Appendix F. The children were transported by taxi during school hours to the Speech Communications Laboratory at Northeastern University, a distance of about 3 miles from the school. Eight of the subjects completed the planned nine weeks' program. Five discontinued the program before the end of the nine weeks for various reasons.

The subjects were selected by the principal and assistant principal of the Horace Mann School as children who were emotionally suited for, and could probably benefit from, the training program. The program had been outlined in detail to the school administrators so that they might select appropriate children.

Audiological criteria were not used, except for the criterion that children be enrolled in the regular deaf classes of the school for the deaf. Previous work with deaf adults on this project, and research with the Voice Visualizer Pronovost [32] had not revealed any relationship between the amount and type of hearing loss and the response to visual speech equipment and programs.

C. Experimental Methods

1. Rationale

This study was designed to determine the effectiveness of a teaching program for deaf children using the IPPI for self-monitoring of imitations of various intonation patterns.

Throughout the two-year research project, one of the major concerns was the nature of the teaching program to be used in conjunction with the IPPI. Therefore, the results of the research with deaf adults were analyzed to determine implications for the program for children. The experience with deaf adults indicated that the sustained-tone tasks were difficult and apparently were not related to tasks required for spoken words and phrases. It was also noted that the rhythm patterns of the speech of deaf adults was frequently faulty and that preliminary work on fluent rhythm and stress patterns was a prerequisite to the work on intonation. Therefore, training sessions and test tasks were developed for rhythm and stress patterns, since these could be displayed on the IPPI screen, and monitored visually by the deaf children.

The design of the children's program was based in part on the results of the Voice Visualizer research [32] in which two of the current investigators had participated. This research indicated the need for test tasks which could identify areas of strength and weakness in vocal ability, the need for a variety of tasks, the probability that most learning would occur early in the program, the probability that a short-term program would produce results, and the need for measuring progress at stages throughout the program.

The subjects for the study were selected from the middle and upper school of the Horace Mann School for the Deaf, on the assumption that children in those age ranges would be able to respond to the IPPI. The measure of improvement of intonation usage by the deaf children was the same as that used for the deaf adults, i.e., comparison of tape recordings of the children's speech at the beginning and end of the program. However, it was also desired to determine whether the amount of improvement differed at different stages of the teaching program. Therefore, tape recordings were made at two-week intervals throughout the experimental training program, and analyzed in order to compare the amount of improvement from one test period to another and to determine the stages of the program at which the greatest improvement took place.

Experience with deaf adults indicated variation in the ability of individual adults to perform the tasks of the training program. Some tasks could be performed upon the first attempt while others required a training period. Individuals varied in the tasks that they could perform most readily and the length of time required to learn a task. Therefore, a test battery of tasks to be learned was constructed and included at each of the test periods. Training between test periods was focused on those tasks which a child had not performed satisfactorily in a particular test, so as to determine whether a program of drill could improve ability to perform the task.

Throughout the research, the staff assumed that there probably was a sequence of presentation of tasks which should be followed by each subject in order to complete the training program successfully. Unfortunately, the research with deaf adults did not provide any data that would identify the sequence to be used. Therefore, the staff devised a sequence that was assumed to progress from easy tasks in which all children could succeed at the outset through tasks of increasing difficulty where learning would occur as the result of the training program use in conjuction with the self-monitoring provided by the IPPI. The test tape recordings taken at two-week intervals should provide data on the effectiveness of the sequence devised.

Observations of the work of Helen Woodward at the Central Institute for the Deaf indicate a variety of intonation patterns being taught to deaf children, most of which could be displayed for self-monitoring on the IPPI screen. These intonation patterns were introduced into the training program.

The staff also felt that the children and teacher might develop new activities and ways of using the IPPI, if given the opportunity. Therefore, provision was made for spontaneous activities during portions of each session occurring between testing periods.

All of the factors contributed to the design of the training program and test battery.

2. The Training Program

The experimental program had three aspects: (1) a series of test tasks in rhythm and intonation, administered as a test battery at the beginning of each two-week period; (2) a fifteen-minute drill program during each session on tasks which the children could not do during the testing session; (3) a fifteen-minute informal lesson using spontaneous material and activities initiated by both the teacher and the child. Some of the materials and activities of this program were based on the work of Helen M. E. Woodward [44, 45] at the Central Institute for the Deaf.

The complete training program involved four two-week periods, resulting in a total of eighteen testing and training sessions. Sessions were held twice weekly for one half hour each.

a. Battery of Test Tasks

The teacher produced the indicated stimulus patterns on the IPPI screen, The child was asked to imitate the teacher's pattern. All testing sessions were tape-recorded for future data analysis. The teacher also tabulated the number of correct responses for each task.

Task 1: Production of continuous stream of nonsense syllables:

(a) The child was asked to produce eight repetitions of the unstressed syllable "bu" [bə]* in two seconds. The stimulus pattern on the IPPI was:

____ ____ ____ ____ ____ ____ ____ ____ .

(b) The child was asked to produce four repetitions of the stressed syllable "bah"['ba:] in two seconds. The stimulus pattern was: _____ _____ _____ _____ .

Task 2: Production of combinations of long and short nonsense syllables in typical rhythm patterns of speech.

The child was asked to produce each of the following in imitation of the teacher's stimulus. Syllable stress was to be accomplished by longer syllable duration with no pauses between syllables. The teacher's stimulus pattern remained on the IPPI screen and the child monitored his attempts to match the patterns.

(a) "bu bah" [bə 'ba:] ____ ______

(b) "bah bu" ['ba: bə] ______ ____

(c) "bu bu bah" [bə bə 'ba:] ____ ____ ______

(d) "bu bah bu" [bə 'ba: bə] ____ ______ ____

(e) "bah bu bu" ['ba: bə bə] ______ ____ ____

---

*Northampton Chart symbols are presented in quotes, international Phonetic Alphabet symbols in brackets.

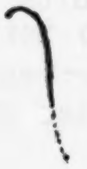
(f) "bu bah bu bu bah" [bə 'ba: bə bə 'ba:]

(g) "bu bu bu bah bah" [bə bə bə 'ba: ba:]

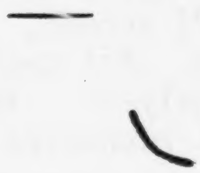
(h) "bah bu bu bah bu" ['ba: bə bə 'ba: bə]

Task 3: Production of pitch changes on nonsense syllables of the same rhythm patterns as Task 2. The following stimulus intonation patterns were used.

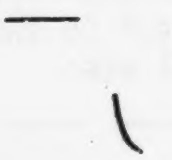
(a)



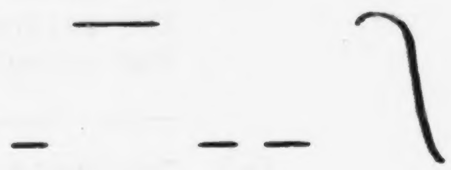
(e)



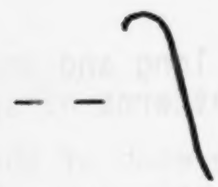
(b)



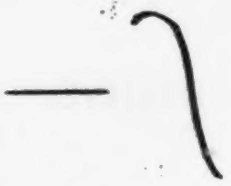
(f)



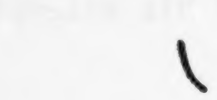
(c)



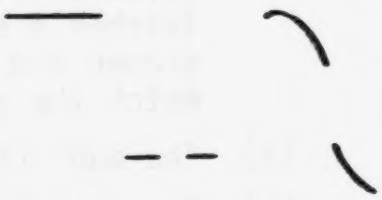
(g)



(d)



(h)



*Northampton Chart symbols are presented in quotes. international Phonetic Alphabet symbols in brackets.

Task 4: Production of pitch changes using words and phrases. Stimulus patterns on the IPPI were the same as for Task 3, but the responses were three words or three phrases for each pattern, as follows:

(a) a ball. a dog. good-bye.

(b) mother. baby. daddy.

(c) in the boat. on the bed. I saw a bird.

(d) I like you. tomorrow. I'm a big boy.

(e) elephant. birthday cake. yesterday.

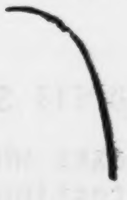
(f) I am reading a book. The boy is feeding his dog. I am going to bed.

(g) I have a red ball. We have a big boat. He found a brown dog.

(h) I live in Boston. My car is yellow. Where are you going?

Task 5: Production of downward inflections:

Pattern=



(a) diphthongs - first part prolonged:
"boi" [bɔI], "bi-e" [baI], "bo-e" [bou]

(b) prolonged vowels:
"bah" [ba:], "bēē" [bi:], baw [bɔ:]

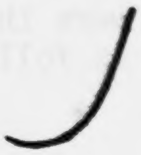
(c) syllables:
"um" [ʌ:m], "un" [ʌ:n], "ul" [ʌ:l].

(d) words: go, run, move

(e) phrases (downward inflection on last word):
That's mine. Where did you go? Her baby's a boy.

Task 6: Production of rising patterns:

Pattern =



(a) Raise pitch in discrete steps:

bu____

bu____

bu____

bu____

(b) diphthongs: (same syllables as in Task 5a)

(c) prolonged vowels: (same syllables as in Task 5b)

(d) words: go? run? move?

(e) phrases: (upward inflection on last word)

Is it good? Is your dog brown? Are you going home?

b. Examples of Procedures Used in Drill Sessions

These sessions were limited to tasks which a child had not performed successfully during a testing period. The teacher presented the following tasks according to the child's individual needs. The teacher produced the stimulus patterns on the IPPI screen and the child attempted to imitate them. Following each session the teacher made an evaluation of the child's progress.

Task 1: Production of a continuous stream of nonsense syllables:

(a) Eight repetitions of the unstressed syllable "bu" [bə] in two seconds.

(1) The child attempted to produce two repetitions in two seconds and to gradually increase the number of repetitions.

(2) The child practiced with various nonsense syllables: ("du" [də], "mu" [mə]).

(b) Four repetitions of the stressed syllable "bah" ['ba:] in two seconds. The child attempted to sustain the stressed syllable for two seconds. He progressed to two repetitions in two seconds and gradually increased the number of repetitions.

Task 2: Production of combinations of long and short nonsense syllables in typical rhythm patterns of speech.

(a) The child practiced the rhythm patterns presented to him in random order.

(b) The child attempted to produce the following series of vowels:

(1) short vowel repetitions followed by a long vowel:

("bu bu bu bu bu bu bah" [bə bə bə bə bə 'ba:])

(2) short vowel repetitions separated in the middle by a long vowel:

("bu bu bu bah bu bu bu" [bə bə bə 'ba: bə bə bə])

(3) a long vowel followed by repetitions of a short vowel:

("bah bu bu bu bu bu bu" ['ba: bə bə bə bə bə bə]).

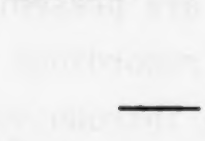
(c) The child practiced with various nonsense syllables such as: "bu bee" [bə 'bi:]. "bu boo" [bə 'bu:]

Task 3: Production of pitch changes on nonsense syllables of the same rhythm patterns as Task 2.

(a) The child practiced the pitch changes presented to him in random order.

(b) The child attempted to exaggerate the pitch change.

"bah bu" ['ba: bə]

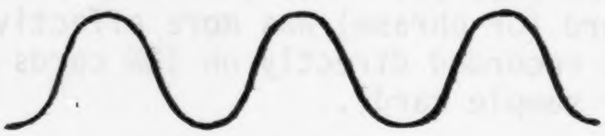


(c) The child attempted to produce diphthongs which use a falling inflection:

("boi" [bəI], "bo-e" [bou]).

(d) The child attempted to produce a continuous rising and falling tone:

"ah" [a]



Task 4: Production of pitch changes (presented in Task 3), using words and phrases:

(a) The child attempted to produce monosyllabic words, containing diphthong (boy, hi, go) and using a downward inflection.

(b) The child viewed pictures which could be associated with the test words and phrases, in order to produce more emotionally charged responses.

(c) The child attempted to sing the melody of familiar songs (Happy Birthday, Mary Had a Little Lamb).

Task 5: Production of downward inflections, and

Task 6: Production of rising patterns:

(a) The child practiced the nonsense syllables and words presented to him in a random order.

(b) The child attempted to recite two syllable words which required a downward inflection (Mother! Bobby!) or upward inflection (Mother? Bobby?)

3. Procedures for Recording and Analyzing Data

a. Clinical impressions of research teacher.

The research teacher of the deaf maintained anecdotal notes of each session with each child. Reports on individual children are included in the case studies in Appendix F. Impressions of the group as a whole were summarized and are presented in the Results section of this report.

b. Tape recordings and listener analyses.

During the introductory session with each subject, a tape recording was made following each four sessions of training (approximately every two weeks) for a total of five tape recordings for each child.

A representative sample of items from each task was selected for the listener tapes to be used in judging improvement of intonation patterns. The test items judged are given in Appendix G. Two test periods were compared by re-recording the same test item from each tape in matched pairs, with the order within the test pairs randomized throughout the series. Listeners judged which of the two utterances (first or second) of the same word (or phrase) was more effective in intonation pattern. Judgments were recorded directly on IBM cards by each listener (see Appendix G for sample card).

A 500 Hz tone of 2 sec. duration was recorded on the tape between the two test utterances to signal the listener that one test utterance was completed and another utterance of the same item would be heard. This was necessary because some utterances were not easily intelligible to a listener, even with the written phrase as a reference. A silent period of 5 seconds occurred between test items to permit listeners time to record judgments on the IBM cards. The following test tapes were compared:

Test 1 and Test 2 (two weeks)
Test 2 and Test 3 (two weeks)
Test 3 and Test 5 (four weeks)

Since it had been observed that improvement tends to occur more rapidly in the early parts of the training program, it was not deemed necessary to compare Tests 4 and 5.

A listening panel of six individuals who were members of a summer theater company were trained to make judgments according to the criteria established - that the judge would indicate which of the two utterances used the more effective intonation pattern. Five of the six listeners had previous training in phonetic transcription of normal and dialectal speech.

The small listening panel was also adopted because there was a need for the same listeners to judge all speakers and all test items. In addition, the small panel permitted the use of headphones so that outside noise interference could be minimized and listening could be at a comfortable loudness for each listener. Additional details of data analysis are presented in connection with the presentation of results in Section VI-D.

D. Results

1. Responses of children to the program.

Eight of the 14 children who began the program completed the entire training program and all five tests. The six who did not complete the program withdrew for a variety of reasons: some personal, some emotional, some because they completed all tasks successfully early in the program, some because they were not sufficiently motivated. Table IV shows the total amount of training received by each subject.

Table IV. Amount of Training Time with IPPI for Deaf Children

Subject	Hours of Training
II-A	8
II-B	10
II-C	9
II-D	8
II-E	10
II-F	9
II-G	9
II-H	9
II-I	8
II-J	8
II-K	7
II-L	3 1/2
II-M	8
II-N	3

The following is a summary of the spontaneous activities initiated by the research teacher and the children during the program:

(1) role playing

(a) fairy tales

The teacher told the children a familiar fairy tale story, e.g., The Three Bears, Little Red Riding Hood, while writing key phrases on the blackboard. The children acted out the story, using speech. The expressions they used were then practiced on the oscilloscope.

(b) emotional situations

The teacher wrote a list of one-word exclamations on the blackboard, e.g., wow, stop, ow, no. She and the children took turns presenting situations which evoked a response of one of the exclamations, e.g., "What would you say if your parents gave you a new bike and a football? The exclamations used were then practiced on the oscilloscope:

(2) storytelling

(a) made-up

The child made up a story which he recited while viewing the oscilloscope.

(b) real experience

The child related an experience to the teacher. Grammatical sentences were constructed which the child practiced on the oscilloscope.

(3) story reading

The child read aloud a story and produced selected expressions on the oscilloscope.

(4) exchange of roles

The child assumed the teacher's role and produced pitch patterns on the oscilloscope which the teacher tried to imitate.

(5) association of expressions with pictures

The teacher presented the child with situational pictures for which the child thought of an appropriate statement. The child's response was practiced on the oscilloscope.

(6) association of moods with pitch levels

The teacher invented a person whose face was drawn on the blackboard without a mouth. She described to the children something which happened to the person, e.g., "Mary tripped on the doorstep. She fell down and skinned her knee." The children were asked to draw an appropriate expression on the face and to indicate how Mary felt, e.g., angry. Finally they were asked what Mary would say, e.g., "Ow! I hurt myself." The teacher associated the mood, e.g., anger, with the appropriate pitch range (e.g. anger is expressed in a high pitch range) and the children practiced the expression on the oscilloscope.

(7) singing

The children attempted to imitate the pitch patterns for a familiar song.

Case study information on each child is presented in Appendix F. The clinical impressions of the research teacher are summarized as follows:

(1) All children showed noticeable and in some cases dramatic improvement in their ability to change pitch.

(2) Seven children approached the rhythm task with emphasis on the number of syllables rather than on the duration of syllables.

(3) All children were able to change their pitch independently of how they performed on the rhythm task.

(4) Four children, after learning to produce a falling inflection, had difficulty reciting the rhythm task items without inflection.

(5) All children found it easier to produce a falling inflection for single words than to produce an intonation pattern for phrases.

(6) All but two children found it easier to produce a falling inflection than a rising inflection.

(7) Five children improved their production of inflections when the task words and phrases were placed in an emotional context.

(8) All children grew to dislike reciting some task items when after several speech sessions they continued to experience failure.

(9) All children became somewhat bored with the test items, particularly those items which had previously been produced correctly.

(10) Four children who learned to produce good pitch changes could not maintain their responses within a normal pitch range. Their habitual pitch levels were too high.

(11) All but two children were able to change pitch without dramatically altering vocal intensity.

(12) All but four children improved their overall vocal quality as they learned the various pitch tasks.

(13) None of the children found it easier to change pitch while attempting to sing.

(14) All children enjoyed making spontaneous utterances in order to create a variety of visual displays on the IPPI screen.

2. Results of Listener Analyses

The testing period of every two weeks was initiated to determine whether change took place during the training program. If so, when did the improvement or regression take place? What type of tasks improved and during what point in the program did these changes take place? Therefore, a complete data analyses would be to compare testing period 1 and 2, 2 and 3, 3 and 4, 4 and 5, and finally 1 and 5 on all test items recorded. The data for such analysis was collected on master tapes; however, before spending the amount of time required in final tape preparation and testing, it was decided to compare test periods 1 and 2, 2 and 3, and 3 and 5, on a more limited number of test items (see Appendix G). It was felt that such a comparison could yield the data necessary to answer the experimental questions. If, however, the data were inconclusive, additional listener comparisons could be made.

The data from the six listeners listening to test 1 and 2, 2 and 3, and 3 and 5 was arranged in the following manner. The three comparisons on each task appeared together for each speaker composing a "cell" for each task for all speakers. The data showing listener judgments for all subjects, tasks and test periods are shown in Appendix H. Table V shows a sample of the data to illustrate the designation of a cell.

Table V. Illustration of Data Comprising a "Cell"

		Subject A	 B
Task 1: Comparison	1-2	6*	3*
	2-3	1	3
	3-5	4	1
Task 2: Comparison	1-2	5*	1*
	2-3	5	6
	3-5	1	4

*Each of these blocks of data, indicating the number of listeners who chose the post-test over the pre-test, was considered a "cell".

If all the six listeners selected the post-test over the pre-test for comparison 1 and 2, for subject "A", a six would appear in the cell in row one. A zero would indicate all listeners preferred the pre-test over the post-test. If five or six of the listeners preferred a post-test response, this was considered to be evidence of improvement. Conversely, a 1 or 0 in a cell which did not contain a 5 or 6 was considered to be evidence of regression. A 2, 3 or 4 preference was considered to be evidence of no change.

To determine whether a change took place, the three comparisons 1-2, 2-3, 3-5, were considered a cell and were analyzed as a unit. For each phrase, it was reasoned that a 6 or 5 in a "cell" indicated an improvement for that task. The relevance of the listener response to the other two test periods would be difficult to determine. In other words, if in a cell all six listeners preferred the second test over the first and in the next comparison only one listener preferred the post-test, as is the case in Table V for speaker A, comparison between 2 and 3, Task 1, the significance of the listeners selecting the pre-test over the post-test in the second comparison could be a function of the nature of the program. When a subject appeared to be able to complete the task, the research teacher would move on to a related and more complex task during one practice session, resulting in some interaction of two acquired tasks. Thus, as a subject moves from practice of a rhythm task to a similar pitch task, the listening panel may have preferred the earlier rhythm response that was closer to the pattern and had no pitch shift.

Twelve subjects speaking 25 phrases resulted in 291 usable cells.* There were 182 cells where 5 or 6 of the listeners responded to one or more of the post-test responses. There were 41 cells where there was no plurality of listeners for the pre-test or post-test, indicating "no change". Sixty-eight cells were recorded as indicating regression. It appears from these analyses that listeners preferred the post-test responses in their comparisons of test periods 1 and 2, 2 and 3, and 3 and 5, since 63% of the cells indicated improvement, 14% no change, and 23% regression. Consequently, listener responses to a comparison of tests 1 and 5 were not obtained at this time. The data from the three comparisons reported here were considered evidence of definite improvement by the subjects during the training program of rhythm and intonation with the IPPI.

In answering the question, "If change took place, during what part of the program did it occur? The program was divided into the tasks related to rhythm, pitch, phrasal intonations, falling inflections, and rising inflections. For each group of program tasks, the number of cells indicating the greatest improvements and regressions were counted. Subsequently, percentages were computed for each group of tasks and each of the three test periods compared. Fig. 19 shows bar graphs of these percentages (and numbers of cells) for the periods in the program when the greatest improvements occurred and also when the regressions occurred.

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*For a variety of technical reasons, nine cells contained no data.

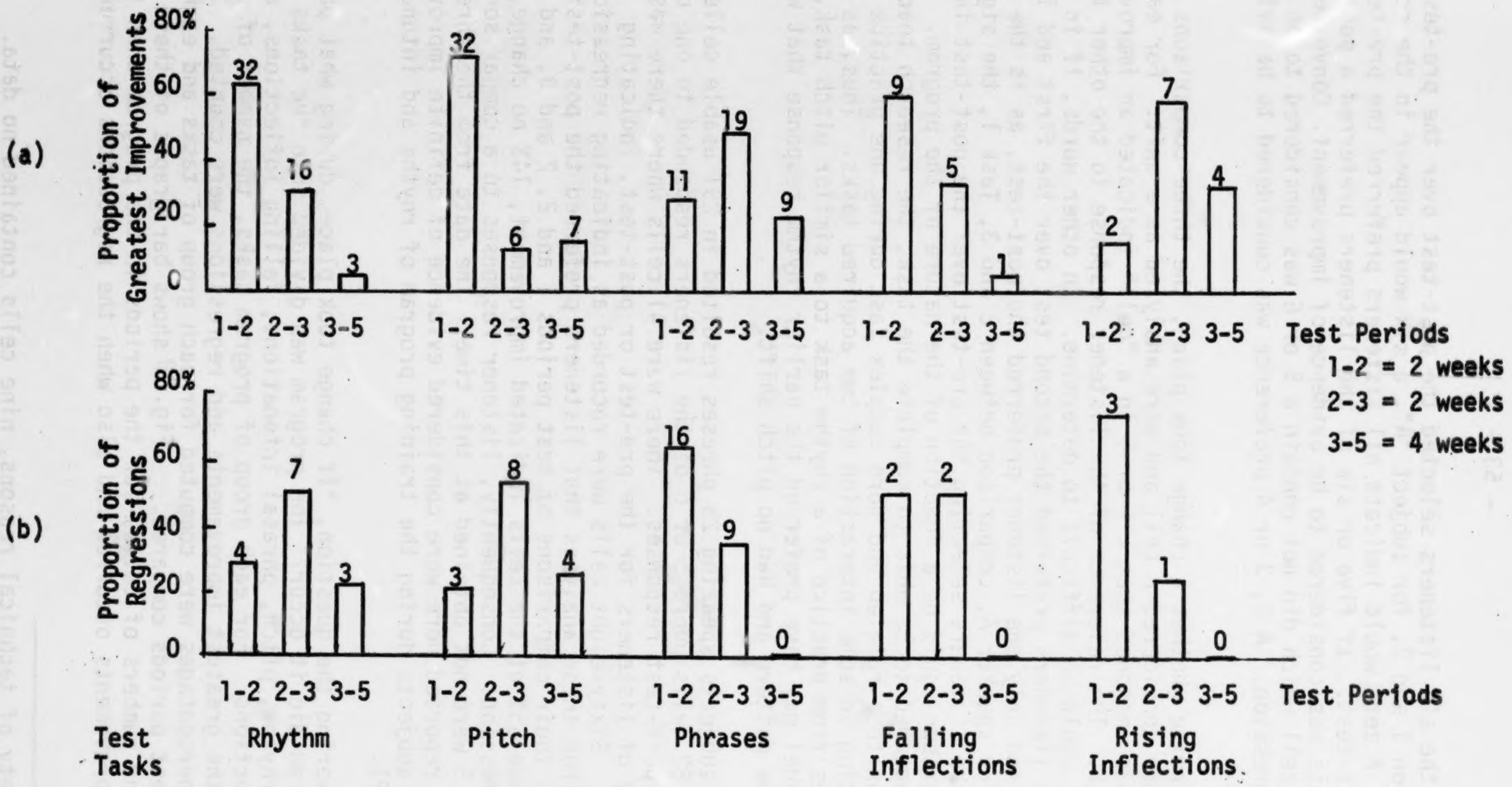

Fig. 19. Bar graph indicating period of training program for which listeners judged (a) post-test over pre-test indicating greatest improvement for each task, and (b) pre-test over post-test indicating regression, or lack of improvement, for each task. For each test task, the proportionate improvement or regression between test periods is indicated. Numbers above bars refer to number of test items for all subjects in which listeners judgments could be categorized as greatest improvement or regression.

Inspection of the "improvement" section of Fig.19 reveals that rhythm, pitch, and falling-inflection tasks were learned during the first two weeks of the program. Additional learning apparently did not occur in later stages of the program, although it must be remembered that the research teacher did not include further training on a task between test periods once she had determined that the tasks had been learned. Tasks involving phrasal intonations and rising inflections tended to be learned in all training periods, but with the greatest improvements occurring between test periods 2 and 3.

Inspection of the "regression" section of Fig.19 shows a slight regression for the rhythm and pitch tasks in the period immediately following the first period when they were learned, but then the regressions decreased considerably during the last half of the program. However, for the three types of tasks involving the use of spoken phrases or expressions, regressions occurred prior to the period of greatest improvement, then decreased, and did not occur at all during the last half of the program. It must also be noted that the number of regressions for each type of task was minimal.

Fig.19 illustrates graphically that learning continued to occur throughout the program, with the learning of rhythm, pitch level, and falling inflection tasks occurring during the first two weeks. Intonation of spoken phrases and falling inflection tasks were learned during the second two-week period. Although great improvement did not continue in the last half of the program, there were no regressions during this period. The data permit the conclusion that the equipment and program were successful in improving the deaf children's ability to control vocal pitch in selected learning tasks involving rhythm intonation and use of pitch inflections.

E. Discussions and Conclusions

The data for this part of the research gives evidence of definite improvements by deaf children in the use of rhythm and intonation patterns of speech, during a training program with the Instantaneous Pitch-period Indicator. Improvements in control of rhythm and pitch patterns with nonsense syllables occurred within two weeks during four training sessions, followed by a test of a few days later. Learning of intonation patterns of spoken phrases tended to occur as a result of four weeks of training. Rising inflections on single-word expressions required four weeks of training, while falling inflections were learned within the first two weeks of the program. For all tasks, improvements during the last four weeks of the eight-week training program were less than improvements occurring within the first or second two-week periods. Regressions occurred to a small degree in early stages of the program but did not occur during the last four-week period. It was observed that the subjects were much less motivated during the latter half of the training program and that the entire program was completed by eight of the fourteen subjects, with six subjects dropping out of the program for a variety of reasons.

From this evidence it is concluded that, for the deaf children included in the program, the training program devised for use with the Instantaneous Pitch-period Indicator was effective within four weeks of training.

The researchers' hypothesis that training in rhythm and pitch patterns with nonsense syllables should precede training in intonation patterns of spoken phrases is substantiated by the data. However, falling intonations were learned earlier than originally assumed while rising intonations were more difficult, as assumed in the program design.

In terms of the goal of determining the sequence of the tasks to be included in a training program, it is evident that the tasks are learned in the hypothesized sequence but in a shorter period of time. The decreased motivation of the subjects, and the failure of continued improvement to occur as the training period was increased, suggests that new tasks need to be introduced. These tasks may need to be new approaches or more complex tasks related to rhythm and intonation patterns of spoken phrases. However, it is also probable that training in tasks related to other attributes of speech is required. It is possible that, as rhythm and intonation improved, differences between pre-and post-tests were more difficult to judge, and that improvement would have been noticeable if training in articulation of vowels and consonants had also been included.

The data indicated a vast improvement of the children's program over the adults' program. This is interpreted to support the revisions of the adult program. In lieu of the adults' better response to speech tasks than sustained vocalization tasks and the children's failure to continue to improve in speech tasks during the latter part of the program, a revision in sequence of those tasks known to be effective seems to be in order. It is suggested that a specific rhythm pattern, once learned, be followed immediately by a spoken phrase in the same pattern as the medium for learning intonation. Thus, instead of continued practice with a certain type of task through several trials and patterns, a child would be trained to apply rhythm and pitch changes to the intonation of a spoken phrase immediately, thus applying the learned vocal skills to the spoken phrases throughout the entire training program rather than only in the later stages of the program. The later stages of the program would then be devoted to more complex rhythm and intonation patterns of spoken phrases and sentences.

In spite of the fact that training between test periods was devoted to tasks which a child could not perform, and that provision for spontaneous activities with the equipment initiated by children and teacher, variability in the response of children to the program were observed. This variability may be due in part to the variability in the needs and abilities of the subjects. The researchers infer from their experience that a larger number and variety of tasks were required, but that provision must be made in further research for selection of tasks most appropriate for each individual subject. A study on the sequence of tasks for a training program, using programmed-instruction approaches in connection with the establishment of a base line for each subject, seems indicated as the next phase of research in the use of visual feedback of speech information for self-monitoring by deaf children.

VII. PITCH INDICATOR MODEL III (IPPI-AID)

A. System Objectives.

In the course of the previous work of this research group with the various models of the Instantaneous Pitch-period Indicator, it became desirable to develop a new portable model which would incorporate a number of desirable features not included in previous models. In the design of this new unit, called IPPI-AID, (Instantaneous Pitch-period Indicator - Amplitude, Intonation, Duration), it was decided to follow the objectives and incorporate certain features listed below:

(1) A portable pitch/intensity display, entirely enclosed in the main frame of a storage oscilloscope.

(2) Major emphasis on the clarity of the intonation display.

(3) Simplified operation, so that a child could run the equipment alone.

(4) Automatic erasing of the pattern and triggering without the confusions mentioned before (see Sec. VI-A-1).

(5) Sufficient flexibility of equipment operating modes, to allow accommodation of various teaching programs.

(6) Indication of vocal intensity.

(7) A mirror to allow for visual monitoring of the subject's own, as well as the teacher's, facial movements without excessively disturbing his monitoring of the visual pattern.

(8) High-level earphone amplifiers for auditory feedback.

In the following paragraphs, it will be explained how the various objectives were implemented.

Ad (1): In constructing the new unit the Hewlett-Packard 141 A variable-persistence oscilloscope was used in place of the previously used Tektronix 564. The storage of the visual pattern in the new oscilloscope is based on a different principle, which allows the use of phosphors which are more resistant to burning. Thus the probability of a permanent damage to the display medium due to phosphor burning is very much reduced. Also, a high constrast in the minimum fade (or long persistence) mode of operation is obtained. In addition, the variable persistence which is available permits a greater flexibility in the presentation of patterns.

Ad (2): The philosophy followed in obtaining a clear intonation display is presented in Sec. VII-C-1.

Ad (3): In order to make it possible for the unit to be used by a school child in the absence of the teacher, only essential controls are accessible to the subject. Other controls, which might cause misalignment of the unit, are not accessible to the subject but can be reached through small openings in the panel (see Fig. 20). In this way, excessive distraction of the subject due to the manipulation of these additional controls is also eliminated.

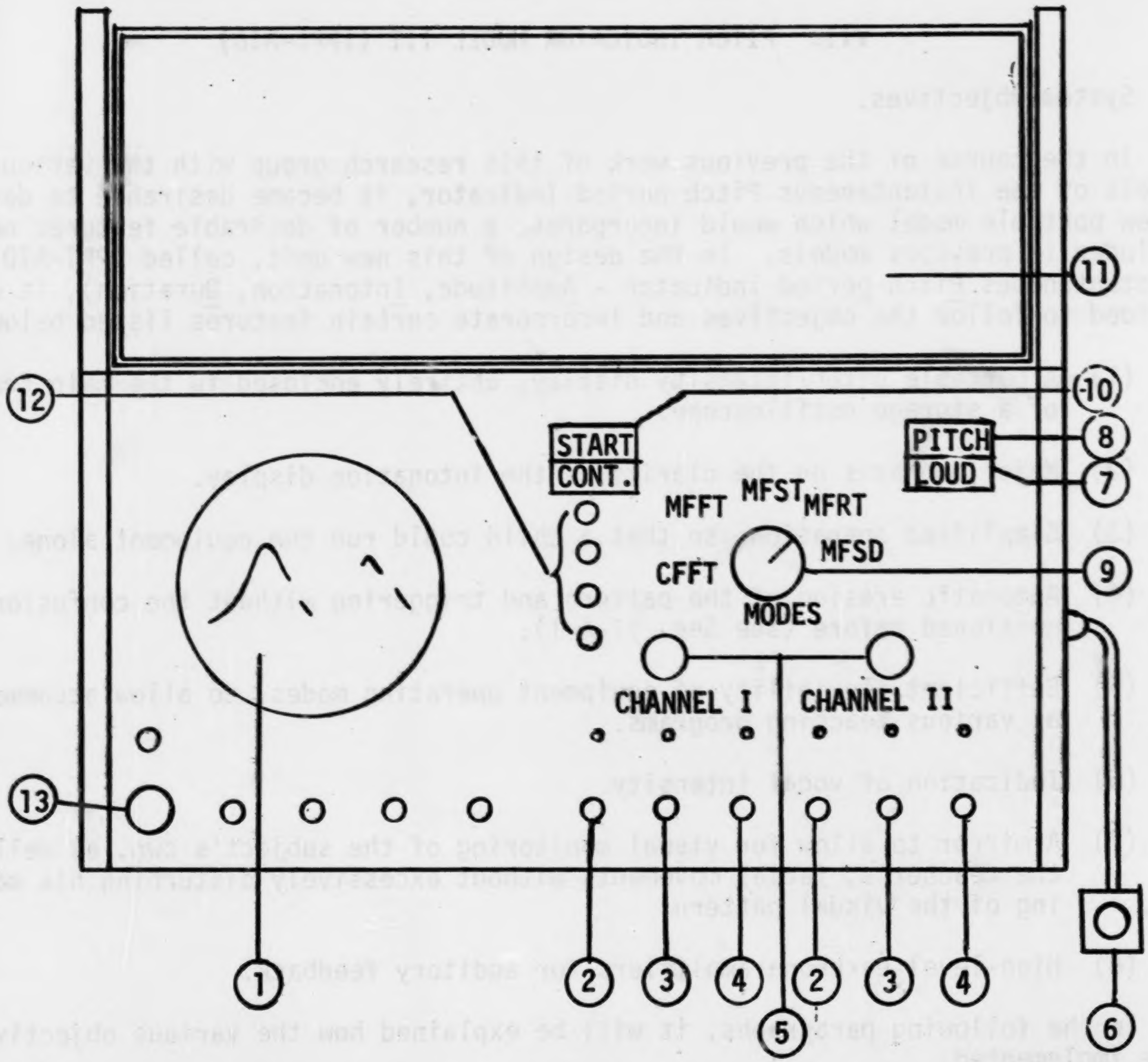
START
CONT.
PITCH
LOUD
MFFT
MFST
MFRT
MFSD
CFFT
MODES
CHANNEL I
CHANNEL II
11
10
12
8
7
9
13
1
2
3
4
2
3
4
5
6

Fig.20. Front view of IPPI-AID; (1) display screen; (2) microphone jack; (3) earphone jack; (4) auxiliary input; (5) habitual pitch level control; (6) plug-in trace width control; (7) intensity control switch; (8) pitch control switch; (9) mode selector; (10) sweep status indicator and reset button; (11) mirror; (12) vocal intensity lights; (13) power switch.

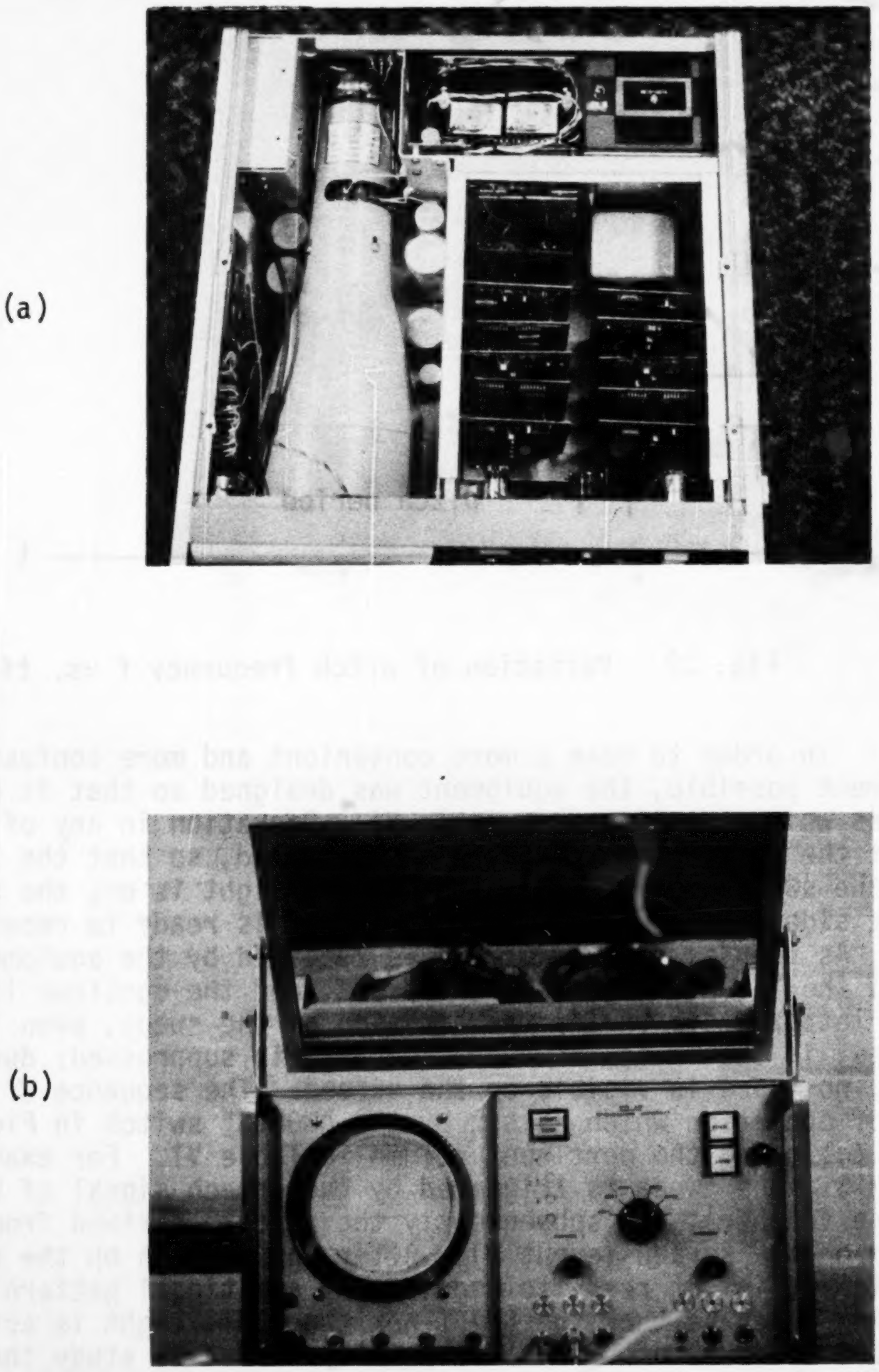

Fig. 21. Instantaneous Pitch-Period Indicator Model III (IPPI-AID): (a) top view, with mirror and top cover removed, (b) front view.

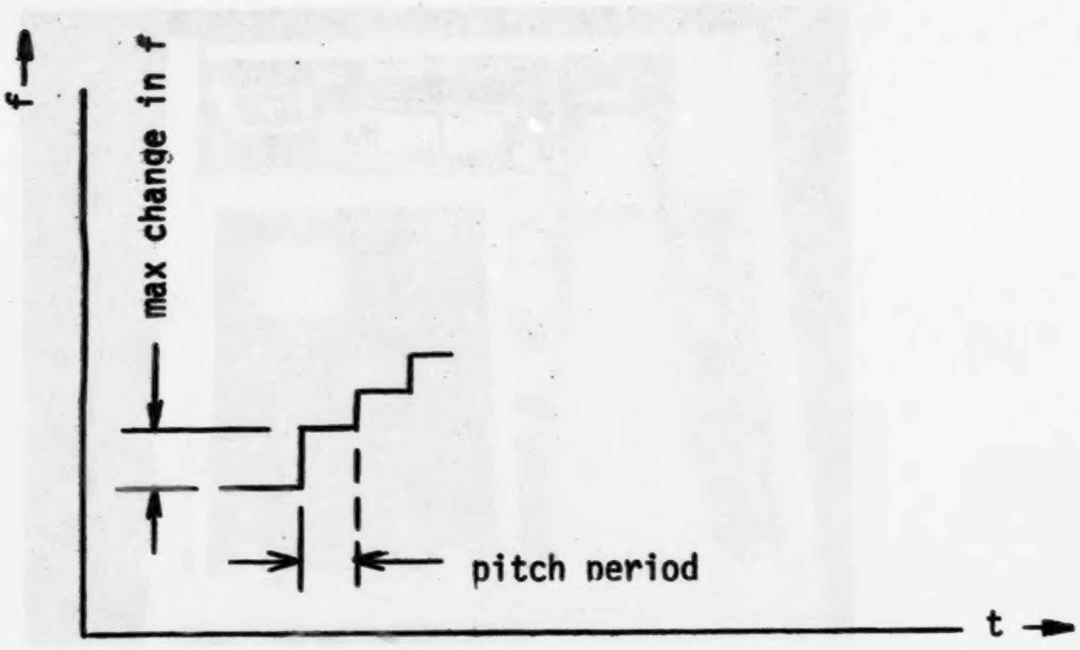

Fig. 22. Variation of pitch frequency f vs. time t.

Ad (4) and (5): In order to make a more convenient and more confusion-free usage of the equipment possible, the equipment was designed so that it can operate in a number of modes which are listed in Table VI. Operation in any of the listed modes presumes that the "PITCH" switch has been activated, so that the light under the pushbutton of the switch is on. When the "START" light is on, the cathode-ray beam is on the left side of the screen - the equipment is ready to receive and display a pattern. As soon as a sound signal is received by the equipment, the sweep is triggered, the "START" light is turned off, and the continue light "CONT." is turned on. The latter stays on for the duration of the sweep, even if the speech signal ceases; in that case, however, the beam is suppressed; during the moments of silence, no trace is visible on the screen. The sequence of events for a particular mode of operation which is set by the "MODES" switch in Fig. 20, is best understood by following the pertinent column in Table VI. For example, when operating in Mode MFST, the sweep is triggered by the speech signal of Channel 2 (usually used by the teacher), and subsequently the pattern derived from this speech signal is displayed on the screen (event 2). After the pattern on the screen is completed, the equipment is not ready to receive any additional pattern for a period of two seconds during which neither the START nor the CONT. light is activated (event 3). This time interval of 2 secs. is usually needed to study the teacher's pattern in preparation for an imitation attempt, whenever he is ready (event 5). The pattern derived from the student's speech signal is then displayed on the screen (event 6), and both patterns remain displayed for a period of 4 secs (event 7). Subsequently, both patterns are automatically erased, and the equipment is ready for a new sequence as soon as the "START" light comes on.

The various modes used in the operation of the equipment are intended to serve the following purposes:

CFFT*: Useful in situations where the subject is monitoring continuous speech.

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* The meaning of the mode designations is evident in Table VI.

TABLE VI. Modes of Pitch Pattern Presentation

Mode	CFFT	MFFT	MFST	MFRT	MFSD
Persistence	Continuously Fading	Minimal Fading	Minimal Fading	Minimal Fading	Minimal Fading
Trigger of Display	Free Triggering	Free Triggering	Sequenced Triggering	Repeated Triggering	Simultaneously Displayed
Sequence of Events					
1 Triggering Channel	1 or 2	1 or 2	2	2	1 or 2
2 Channel Displayed	Triggering Channel	Triggering Channel	2**	2**	1 and 2
3 Storage Time*	Fades Continuously	4 sec.	2 sec.	2 sec.	variable
4 Erasure	↓	Automatically	- - -	*** If manually, go to 1, otherwise continue	manually, go to 1
5 Triggering Channel	↓	↓	1 or 2	1 or 2	↓
6 Channel Displayed	↓	↓	Triggering Channel	Triggering Channel	↓
7 Storage Time*	↓	↓	4 sec.	1 sec.	↓
8 Erasure	↓	↓	Automatic ↓	*** If manually, go to 1, otherwise go to 5	↓
		Ready for New Sequence			

* Delay time after pattern has been produced.

** Channel 2 can produce a double-line pattern with variable spacing between the two lines.

*** Manual erasure by pressing START-CONT button (see Fig. 20).

MFFT: Useful when it is desired to display and study a complete phrase pattern or sentence.

MFST: Suitable for automated programming, or rigidly sequenced lessons.

MFRT: This mode can also be used for automated programming; however, a greater flexibility in the number of responses per stimulus is possible.

MFSD: Useful when the teacher and the subject practice simultaneously, which is sometimes desirable for greater motivation. This mode can also be used in place of MFFT but in this case a variable length of time to study the patterns is available to the subject.

Ad (6): Since the speech volume of many subjects is too low, and also because it is often desirable to show to the subject the difference between intensity and intonation, an intensity display was implemented in the form of a group of four lights. With increasing intensity of the speech signal, more lights are progressively turned on. This display which is activated by means of a loudness switch ("LOUD") can be used either separately, or simultaneously with the intonation display.

B. Mechanical Design.

The front view of the external physical layout is presented in Fig. 20. In this figure, (1) represents the display screen on which the intonation pattern appears. The input signals are connected either to the microphone jacks (2) or the auxiliary input terminal (4). An output for an earphone can be obtained from the earphone jack (3). The habitual pitch-level control (5) makes it possible to shift the intonation pattern on the screen (1) up and down as needed. If it is desired to replace the ordinary intonation pattern by a double-line pattern indicating the limits of acceptability of the response, this can be implemented by connecting a plug-in trace-width control (6) at the side of the oscilloscope unit. The loudness display represented by the four light bulbs (12) is activated by depressing the loudness switch (7). The pitch display (1) is activated by depressing the pitch control switch (8). The various modes of operation can be selected by means of the mode-selector switch (9). The reset button (10) is used for erasing the intonation pattern on the screen, and where applicable, to return the circuits into the initial state preceding a new display sequence. The button also contains two illuminated captions - "START" and "CONT". The mirror (11) is used for monitoring the subject's as well as the teacher's facial movements. It can be adjusted in such a way that the face of the teacher, the face of the student and the display screen (1) can all be seen by the student without moving his head. Finally, the power switch (13) is used to switch the unit on and off.

Photographs of the actually constructed unit are shown in Fig. 21. In Fig. 21a, which represents the top view of the unit, the cathode-ray tube of the oscilloscope is shown on the left, while most of the newly constructed circuits are contained in the removable plug-in unit on the right. The newly constructed circuits are seen to be in the form of removable printed-circuit boards; individual circuits can therefore easily be removed for inspection and testing, and can also be conveniently replaced by an alternative circuit if this should become desirable. In addition to the power available from the main oscilloscope unit, the newly constructed circuits of the plug-in part of the unit use the power supply shown in the upper right-hand corner. In Fig.21b, a photographic view of the front of the unit is given; in addition to the unit itself, the microphone-earphones usually used with the unit are also shown.

C. Pitch Detector Design.

1. Design philosophy.

The basic assumption in the design of the system is that pitch can be visually detected from the speech waveform with such a high degree of accuracy that this manner of pitch detection may be used as a standard in establishing the accuracy of other pitch extraction methods [25]. A number of these pitch extraction methods, including one advanced by Gold [14], require the knowledge of future as well as past points of the speech waveform in the process of establishing the value of the present pitch frequency. In the interest of simplicity of equipment, particularly in order to avoid excessive requirements for storage elements, it is preferable to disregard the future waveform and base the process of establishing the value of the present pitch frequency on the past values of the waveform alone. The occurrence of occasional errors can be minimized by eliminating certain pitch-period identifying information which, in view of the past nature of the waveform and certain physical limitations of the speech-producing mechanism, can clearly be identified as being erroneous. This error suppression can be based on certain limiting parameters which are described in the next section.

2. Limiting Parameters.

The following parameters are used to eliminate erroneous pitch-period indications: (a) total range of pitch frequency, (b) maximum rate of change of pitch frequency.

a. Pitch-frequency range.

Many estimates have been made of the total range of pitch frequencies. These estimates vary greatly, and frequencies as low as 33 (creaking), and as high as 3.8 kHz [26] have been reported. In designing the IPPI-AID equipment described in this chapter, however, it was desired to accommodate only the frequency range of normal speech, plus any additional range which might occur in the speech of the deaf.

b. Maximum rate of change of pitch frequency.

In Fig. 22, an example of the variation of pitch frequency vs. time is shown. It is seen that in this case the maximum rate of change of pitch frequency occurred at the beginning. In general, this maximum rate of change of pitch frequency cannot exceed a certain value due to the physical limitations of the speech-producing mechanism.

3. Logic Design.

a. Relationships between limiting parameters.

In Fig. 23, a sequence of pulses, identifying the beginnings of pitch periods in time, is shown. The first two pulses define a pitch period of a certain duration T = 1/f(R). The logical decisions to be made about the acceptability of the next pitch-period indicating pulse are based on the duration of the first pitch period. In developing the mechanism for these logical decisions, certain quantities should first be defined as follows:

T(HF) is the pitch-period duration for the highest possible pitch frequency, while T(LF) corresponds to the lowest possible pitch frequency. A pitch-period indicating pulse which occurs before T(HF) is terminated must be in error, and is therefore always suppressed. The next condition that a new pitch-period indicating pulse must meet in order not to be disqualified as an erroneous pulse is that it must occur within the interval ΔT. As can be seen from Fig. 23, ΔT is the interval between T(IR) and T(DR). T(IR) and T(DR) are related to the maximum permissible rate of change of the pitch frequency and to the pitch frequency corresponding to the just preceding (acceptable) pitch period as defined in Fig. 23. This test of acceptability is applied only if an acceptable pitch period preceded immediately. The limits of acceptability for the rate of change were obtained from a previous study [9] in which an effort was made to measure the maximum rate of change of pitch frequency that the subjects were capable of performing. Some pertinent results in this study are shown in Fig. 24. If a pitch-period indicating pulse does not occur during the entire duration of T(LF), it is concluded that phonation has ceased and the next pitch-period indicating pulse will be considered to be the beginning of a new voiced utterance.

b. Pattern-onset delay.

Since various randomly occurring noises are usually present before the beginning of a voiced utterance, and since such noises give rise to erroneous pitch-period indicating pulses, it is desirable to eliminate a very short part of the initial portion of the intonation display in order to avoid confusion. Occasionally, the interfering noise pulses cause the pitch indicator to indicate a frequency which is one-half of the correct frequency (i.e. skipping every other pitch-indicating pulse). In order to prevent the perpetuation of this incorrect indication throughout the utterance, a special circuit searches for the correct pitch-indicating frequency, starting from the highest permissible frequency.

c. Suppression of other errors.

If an expected pitch-period indicating pulse does not occur within the interval ΔT, the visual display is suppressed until a sequence of three acceptable pitch periods develops. If, however, an expected indicating pulse does not occur within the interval ΔT or between T(DR) and T(LF), the voiced utterance is considered to be terminated, and the circuit settings return to their initial state, suitable for the beginning of a new voiced utterance.

D. System Outline.

The operation of the pitch/intensity display system is best explained with the help of the block diagram shown in Fig. 25. The microphone signals are amplified by means of either of the two microphone pre-amplifiers and fed to the corresponding mixers which can also accept an auxiliary input signal, for example from a tape recorder. Each of these two mixers feeds a separate pitch detection and pulse-to-analog (P-A) circuit. The outputs of these two P-A circuits are fed to a vertical amplifier via a common switch. The output of the vertical amplifier is used as the vertical deflection voltage for a cathode-ray tube. The horizontal deflection voltage for the cathode-ray tube is generated in the sweep generator, and amplified in the horizontal amplifier. The mode switch, indicated by dashed lines in the diagram, is used to obtain the various sequencing and display operations of the system by adjusting the parameters in the blocks indicated by arrows on the dashed lines. The output of the mixers of channel 1 and channel 2 are used to generate trigger signals which activate the delay and sequencer circuit and the switch control for the channel-selecting switch. In the MFSD mode the switch is under the control of the clock.

f(R) = reference pitch frequency
T(HF) = period of highest possible pitch frequency
T(LF) = period of lowest possible pitch frequency
T(IR) = period of pitch frequency obtained with the highest possible positive rate of change, when starting from the pitch frequency of the preceding pitch period
T(DR) = period of pitch frequency obtained with the highest possible negative rate of change, when starting from the pitch frequency of the preceding pitch-period

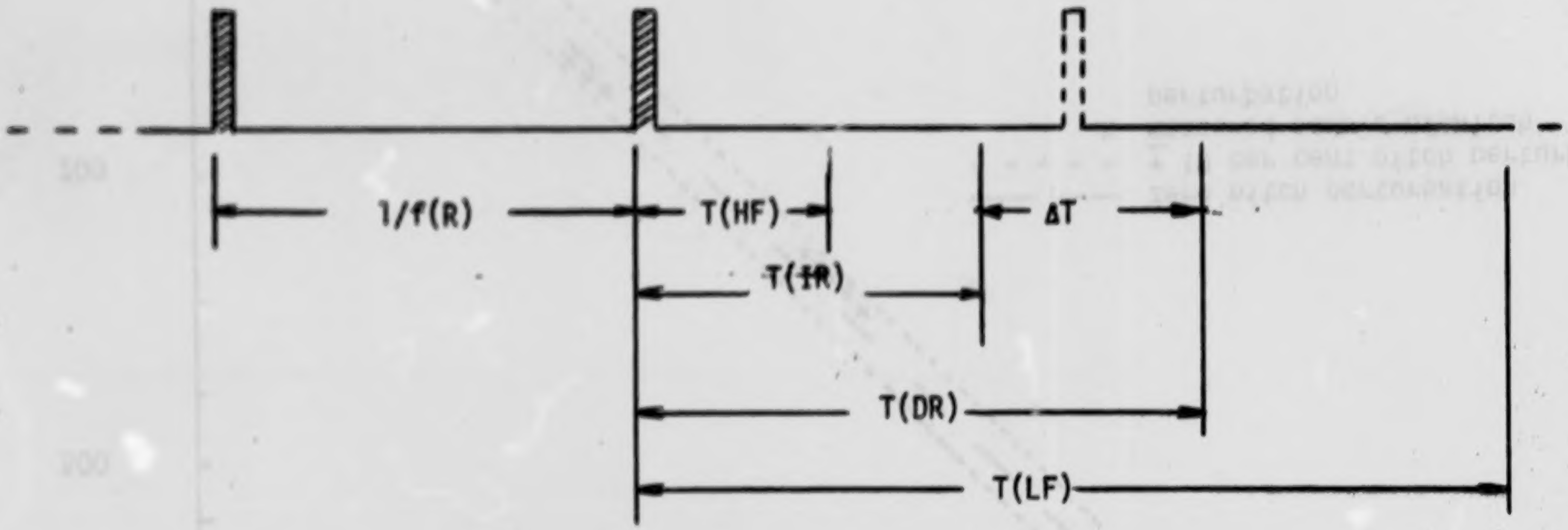


Fig. 23. Output of peak detector showing regions of error suppression.

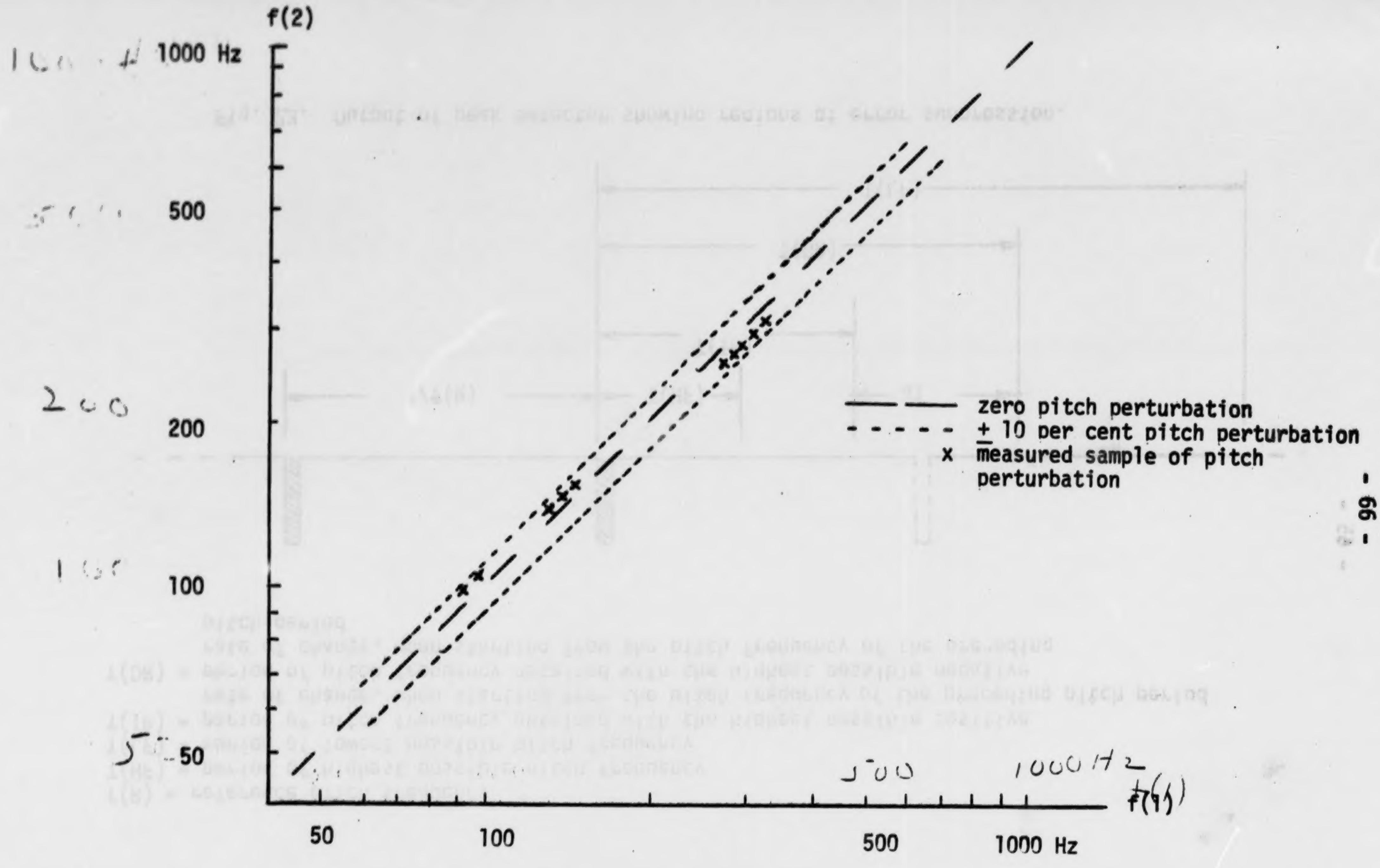


Fig. 24. Relationship between the pitch frequencies of two consecutive pitch periods, f(2) vs. f(1), reflecting the magnitudes of perturbations between the two periods.

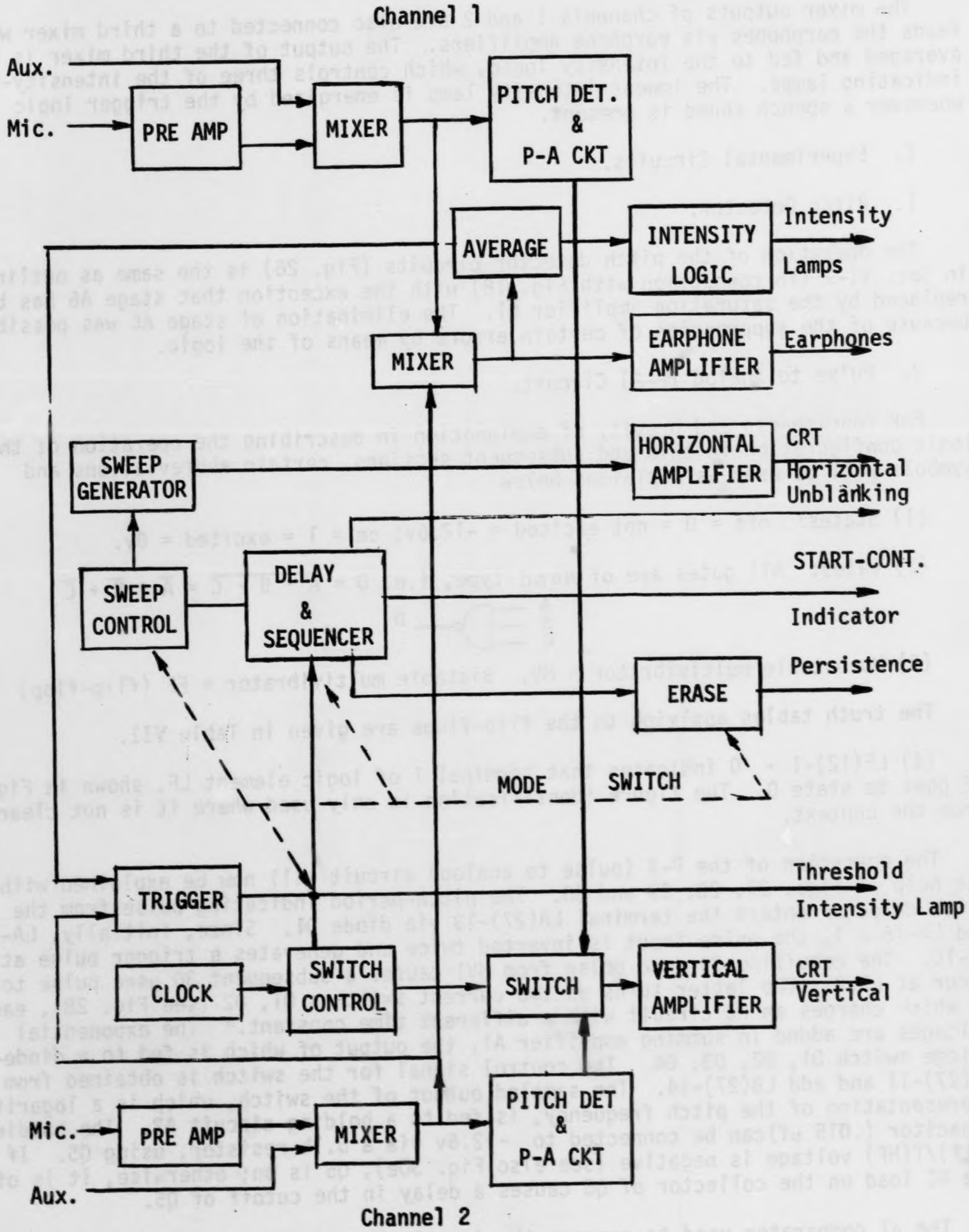

Channel 1
Aux.
Mic.
PRE AMP
MIXER
PITCH DET. & P-A CKT
AVERAGE
INTENSITY LOGIC
Intensity Lamps
MIXER
EARPHONE AMPLIFIER
Earphones
SWEEP GENERATOR
HORIZONTAL AMPLIFIER
CRT Horizontal Unblanking
SWEEP CONTROL
DELAY & SEQUENCER
START-CONT. Indicator
ERASE
Persistence
MODE SWITCH
TRIGGER
Threshold Intensity Lamp
CLOCK
SWITCH CONTROL
SWITCH
VERTICAL AMPLIFIER
CRT Vertical
Mic.
PRE AMP
MIXER
PITCH DET & P-A CKT
Aux.
Channel 2

Fig. 25. IPPI-AID Block Diagram

The mixer outputs of channels 1 and 2 are also connected to a third mixer which feeds the earphones via earphone amplifiers. The output of the third mixer is also averaged and fed to the intensity logic, which controls three of the intensity-indicating lamps. The lowest-intensity lamp is energized by the trigger logic whenever a speech sound is present.

E. Experimental Circuits.

1. Pitch Detector.

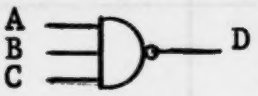
The operation of the pitch detector circuits (Fig. 26) is the same as outlined in Sec. VI-2 (in connection with Fig. 18) with the exception that stage A6 has been replaced by the saturation amplifier Q1. The elimination of stage A6 was possible because of the suppression of certain errors by means of the logic.

2. Pulse to Analog (P-A) Circuit.

For conciseness and brevity of explanation in describing the operation of the logic configuration in this and subsequent sections, certain abbreviations and symbols will be used as explained below:

(1) States: off = 0 = not excited = -12.6v; on = 1 = excited = 0v.

(2) Gates: All gates are of Nand type, i.e. $D = \overline{A \cdot B \cdot C} = \overline{A} + \overline{B} + \overline{C}$



(3) Monostable multivibrator = MV. Bistable multivibrator = FF (flip-flop)

The truth tables applying to the flip-flops are given in Table VII.

(4) LF(12)-1 → 0 indicates that terminal 1 of logic element LF, shown in Fig. 12 goes to state 0. The figure identification is only used where it is not clear from the context.

The operation of the P-A (pulse to analog) circuit will now be explained with the help of Figs. 27, 28, 29 and 30. The pitch-period indicating pulse from the pitch detector enters the terminal LA(27)-13 via diode D1. Since, initially, LA-14 and LA-15 → 1, the pulse input is inverted twice and generates a trigger pulse at LB-10. The resulting 30 μsec pulse from MV1 causes a subsequent 30 μsec pulse to occur at LB-2. The latter turns on two current switches Q1, Q2 (see Fig. 28), each of which charges an RC circuit with a different time constant.* The exponential voltages are added in summing amplifier A1, the output of which is fed to a diode-bridge switch D1, D2, D3, D4. The control signal for the switch is obtained from LB(27)-11 and add LB(27)-14. The sampled output of the switch, which is a logarithmic representation of the pitch frequency, is fed to a holding circuit A2. The holding capacitor (.015 μf) can be connected to -12.6v via a 5.1k resistor, using Q5. If the T(LF)/T(HF) voltage is negative (see also Fig. 30e), Q5 is on; otherwise, it is off. The RC load on the collector of Q6 causes a delay in the cutoff of Q5.

The ΔT comparator used to compare the durations of consecutive pitch periods is shown in Fig. 29. The summing amplifier output A1(28)-6 and the log (pitch frequency)

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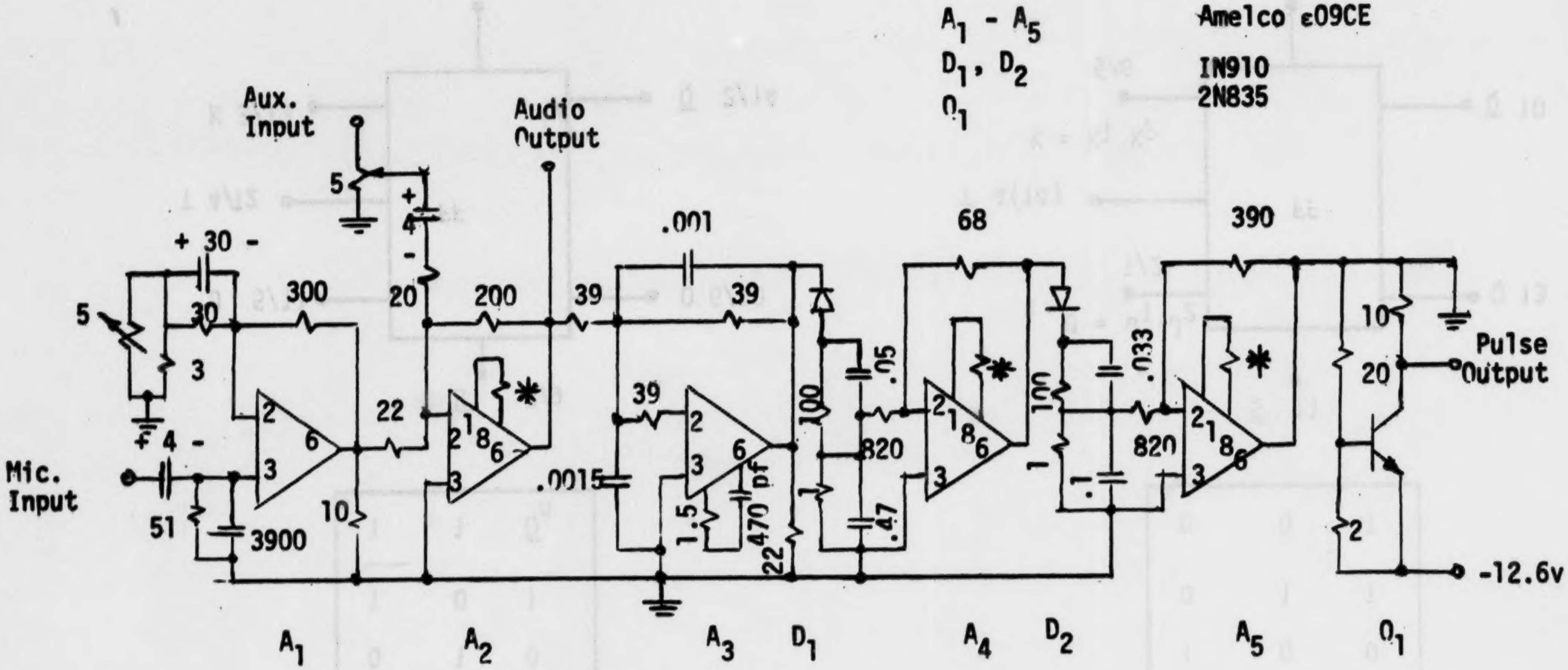
* See Appendix I.


A_1 - A_5 Amelco ε09CE
D_1, D_2 IN910
Q_1 2N835
Aux. Input
Audio Output
Mic. Input
Pulse Output
-12.6v
+ 30 -
5
30
3
+ 4 -
51
3900
300
10
22
20
4
200
39
.001
39
39
.0015
1.5
470 pf
22
100
1
.05
820
.47
68
100
1
.033
.1
820
390
10
20
2
2
3
6
1
8
*
A_1
A_2
A_3
D_1
A_4
D_2
A_5
Q_1

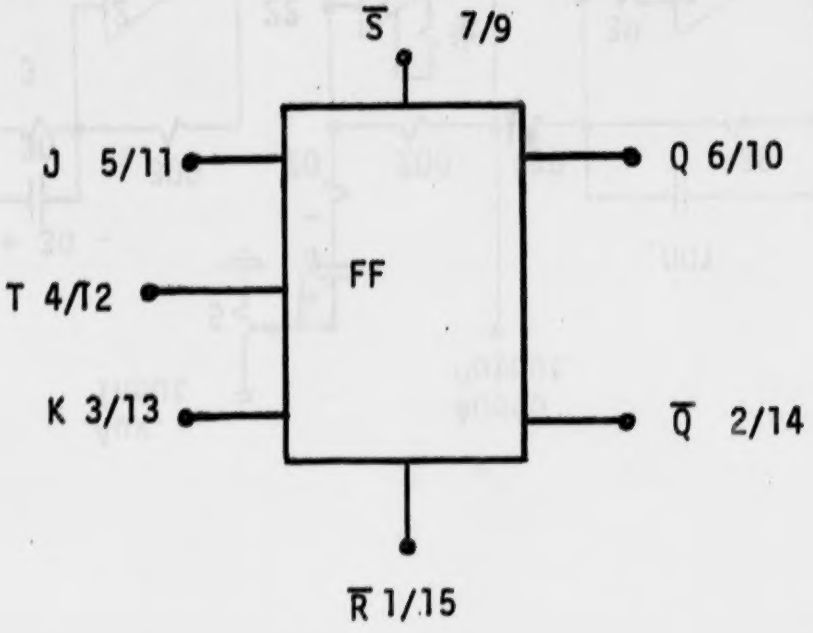
Resistances in kOhm, capacitances in µf unless otherwise specified.
*As needed for zero output.

Fig. 26. Preamplifier, Mixer, Pitch Detector

TABLE VII. Flip-flop truth tables and corresponding diagrams: (a) Amelco logic 312 CJ, (b) Amelco logic 311 CJ

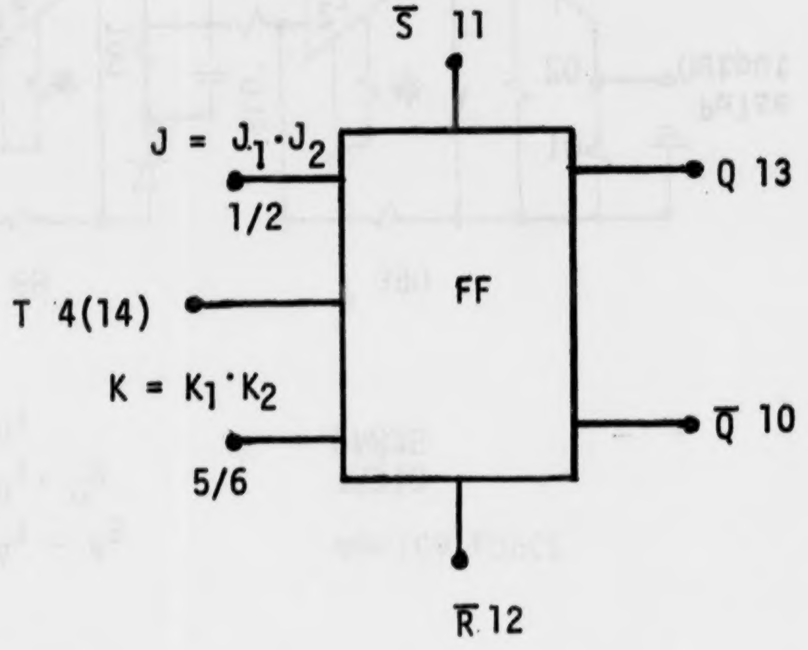
(a)

J	K	Q_{n+1}
0	0	Q_n
0	1	0
1	0	1
1	1	$\overline{Q}_n$


$\overline{S}$ 7/9
J 5/11
T 4/12
K 3/13
FF
Q 6/10
$\overline{Q}$ 2/14
$\overline{R}$ 1/15

(b)

$\overline{S}$	$\overline{R}$	Q
1	1	?
1	0	0
0	1	1
0	0	1


$\overline{S}$ 11
$J = J_1 \cdot J_2$
1/2
T 4(14)
$K = K_1 \cdot K_2$
5/6
FF
Q 13
$\overline{Q}$ 10
$\overline{R}$ 12

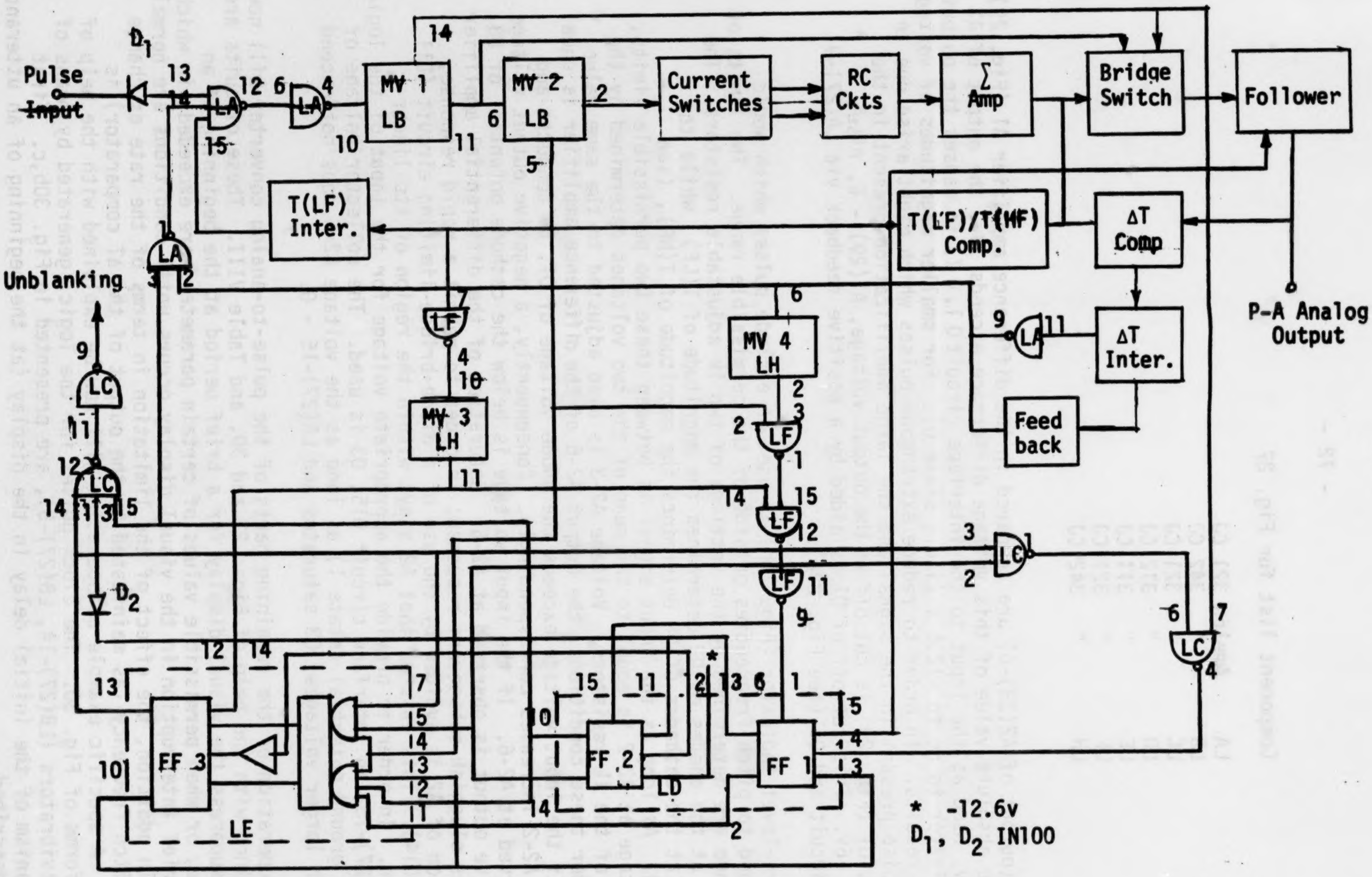

Pulse Input
D1
13
14
12
6
4
15
10
LA
LA
MV 1
LB
11
6
MV 2
LB
5
2
14
Current Switches
RC Ckts
∑ Amp
Bridge Switch
Follower
T(LF) Inter.
T(LF)/T(HF) Comp.
ΔT Comp
ΔT Inter.
Feed back
P-A Analog Output
LA
9
11
1
LA
2
3
Unblanking
9
LC
11
12
LC
14
13
15
D2
LF
7
4
10
MV 3
LH
11
MV 4
LH
6
2
3
2
LF
1
14
15
LF
12
LF
11
9
3
LC
1
2
6
7
LC
4
12
14
13
10
FF 3
LE
7
5
4
3
2
1
15
11
2
13
6
1
*
10
FF 2
LD
14
2
FF 1
5
4
3
* -12.6v
D1, D2 IN100

Fig. 27. (P-A), Pulse Rate to Analogous Log Pitch Frequency Converter.

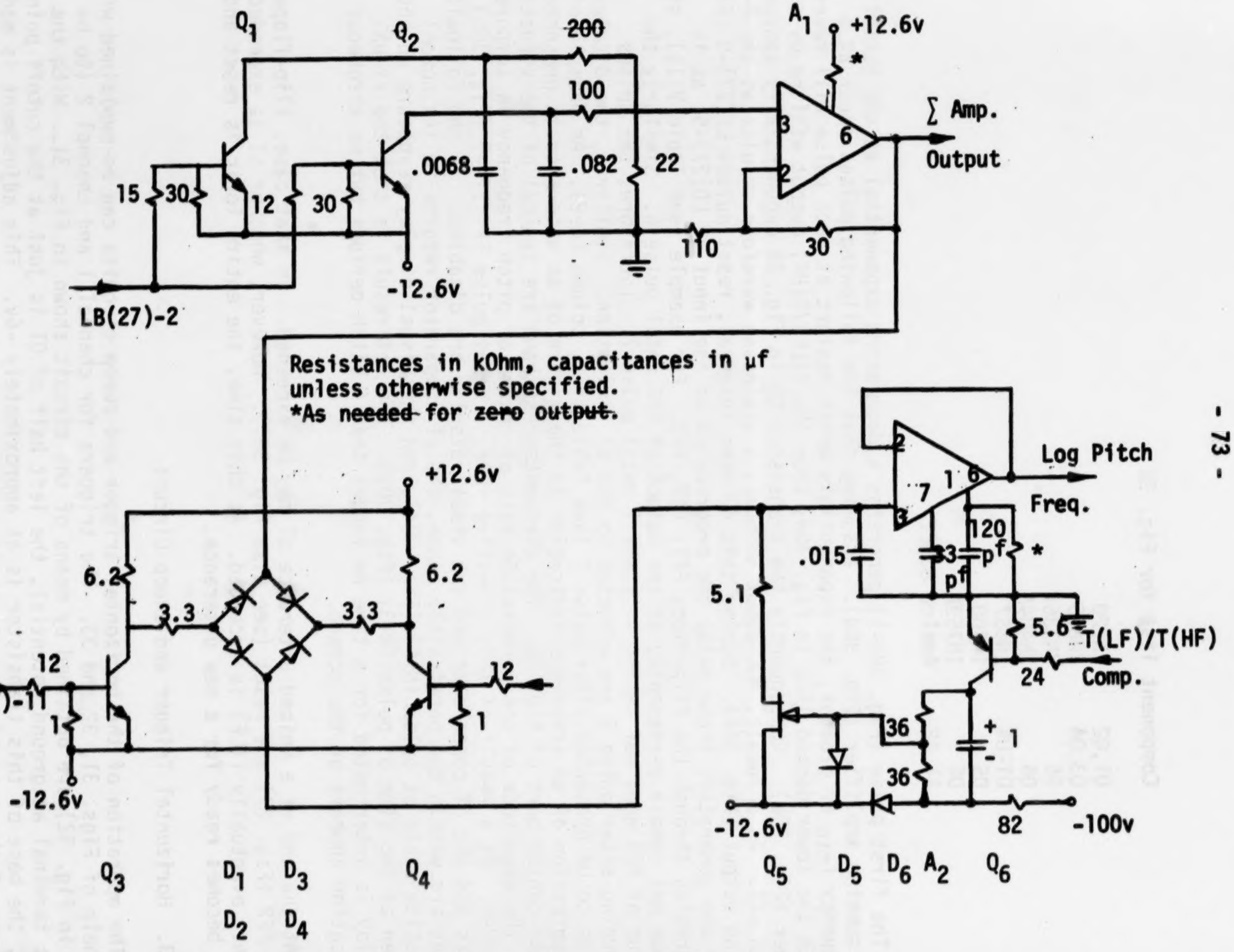
Component list for Fig. 27

LA	Amelco	321 CJ
LB	"	342 CJ
LC	"	321 CJ
LD	"	312 CJ
LE	"	311 CJ
LF	"	321 CJ
LH	"	342 CJ

signal (output of A2(28)-6) are compared in the difference amplifier A1 (Fig. 29). When the absolute value of this voltage difference exceeds .3v, the output of A1 is -12 v. Used as the input to the interface circuit Q1, Q2, it causes the output of the latter to go to -12.6 v (i.e., state 0). For smaller magnitudes of voltage, state 1 results. In order to reduce extraneous pulses which might arise due to minor noise present in the signal and the large amplification present in the circuit, Q1 (Fig. 29) is cut off as the output voltage, A1(29) - 6, rises through -6v. This cut-off of Q1 is aided by a positive feedback via LA(27)-9, an RC circuit and D6 (see Fig. 29a).

A tri-level indicator (Fig. 29b) is used to exclude pulses which would correspond to pitch frequencies outside of the permissible range. The limits of this range are determined by the settings of two 1k adjustable resistors. The voltage at the anodes of D7 determines the magnitude of T(LF), while the voltage at the cathodes of D8 determines the magnitude of T(HF), (see Fig. 23). As long as the input signal is between these two permissible limits, the voltage at A2-2 is equal to the mean of the two voltages determined by the setting of the 1k resistors. Voltage A2-3 is also adjusted to the same value. Thus under these conditions, the output A2-6 of the difference amplifier is equal to 0v. If the input voltage exceeds the anode voltage of D7, D9 conducts and voltage A2-2 increases correspondingly. Consequently, a negative output voltage is observed at A2-6. If the input voltage is below the cathode potential of D8, a positive output is observed at A2-6. Saturation of the differential amplifier A2 causes sluggish subsequent response; in order to permit a rapid response, saturation of A2 is avoided by the use of a diode-bridge-limiting circuit (D11 through D14). This ensures that A2 stays within the region of its linear operation. In order to provide the appropriate voltage for the input of the logic gate LA(27)-15, an interface circuit D15, Q3 is used. The collector voltage of Q3 is at ground potential (state 1) as long as the voltage A2-6 does not exceed +3v. For larger voltages, Q3 saturates and LA(27)-15 → 0.

The operation of the remaining parts of the pulse-to-analog converter will now be explained with the help of Figs. 27 and 30, and Table VIII. These circuits are used to suppress the visual display for a brief period at the beginning of an utterance, or when permissible values of certain parameters are exceeded, in which case a brief interruption in the visual display occurs until conditions are normal again. In addition, the effect of the limitation in terms of the rate of change of the pitch frequency (as mainfested by the output of the ΔT comparator) is delayed. A specific example of operation will now be explained with the help of the waveforms of Fig. 30. The clock pulses for the logic, generated by means of two multivibrators (LB(27)-14, LB(27)-5), are presented in Fig. 30b,c. First the mechanism of the initial delay in the display (at the beginning of an utterance) will be described.


Q1
Q2
-200
100
.0068
.082
22
A1
+12.6v
*
3
6
2
∑ Amp.
Output
15
30
12
30
-12.6v
110
30
LB(27)-2
+12.6v
6.2
6.2
3.3
3.3
12
LB(27)-1
1
12
1
-12.6v
Q3
D1
D3
D2
D4
Q4
2
7
1
6
3
Log Pitch
Freq.
.015
33 pf
pf
120
*
5.1
5.6
T(LF)/T(HF)
24
Comp.
36
36
+
1
-
-12.6v
82
-100v
Q5
D5
D6
A2
Q6

Resistances in kOhm, capacitances in µf
unless otherwise specified.
*As needed for zero output.

Fig. 28. (P-A) Experimental Generator and Sample and Hold Circuits.

Component list for Fig. 28

Q1,Q2	2N720
Q3,Q4	2N835
Q5	2N3367
Q6	2N404A
D1-D4	IN457
D5	IN100
D6	IN753A
A1,A2	Amelco 809CE

The first pulse (Fig. 30c-1) generates a decreasing exponential at the output of the summing amplifier (Fig. 30d). Assuming that the following pulses occur at a frequency f_{min} or greater, the exponentials which restart at each pulse will never reach the lower dashed line in Fig. 30d; thus the T(LF)/T(HF) output will be 0v or higher (Fig. 30e). Consequently the transistor Q5 in Fig. 28 exponentially approaches pinch off. As a result, in about 40 msec, a staircase waveform results at the P-A analog output (Fig. 30f). During this 40 msec interval, reset pulses LF(27)-9 (Fig. 30h) are generated; these delay the progression of the input of LD(27)-5, as it progresses through the flip-flops FF1, FF2, FF3. For example (see Table VIII), state 1 does not remain permanently at the output of FF2 until pulse 6. Similarly the output of FF3 does not remain in state 1 until pulse 7. Therefore, the pulses occurring after pulse 6 are affected by the ΔT limitation. Similarly, the display begins to be presented after pulse 7 (see Table VIII, column LC-9). An example of a suppression of an erroneous indication in the middle of an utterance is presented in the center part of Fig. 30. The circumstances shown are typical of the situation when the magnitude of the permissible rate of change of pitch frequency is temporarily exceeded. As a result of this excessive rate, a reset pulse LF-(27)-9 (Fig. 30h) occurs and the ΔT comparator and the visual display are disabled. If the following pulses are within the permissible range, the ΔT comparator returns to its normal operating state at pulse (N+1) (Fig. 30i), and the visual display reappears on the screen at the time of pulse (N+3) (Fig. 30j). The net result is that the visual display is interrupted for a time no longer than 4 pitch periods but no erroneous indication appears on the screen.

At the end of a voiced utterance ΔT may be exceeded. In that case, flip-flops FF1, FF2 (Fig. 27) are reset (see also Fig. 30i). However, whether ΔT is exceeded or not, eventually T(LF) is exceeded. At this time, the entire logic is reset and thus becomes ready for a new utterance.

3. Horizontal Trigger and Sweep Circuit.

The operation of the horizontal trigger and sweep circuits can be explained with the help of Figs. 31, 32 and 33. The triggers for channel 1 and channel 2 (to be used in Fig. 32) are obtained by means of the circuit shown in Fig. 31. With the input terminal at ground potential, the left half of Q1 is just at the cutoff point; i.e., the base of this transistor is at approximately -6v. This adjustment is made by means of the potentiometer in the input connection. In the presence of an audio signal, its positive values make this transistor conduct with the result that Q2 is turned on. The envelope-detection circuit D3 derives a voltage from the output of Q2. The resulting voltage turns Q3 on. Thus in the presence of an audio signal, LA(31)-4 → 1. Similarly, if an audio signal is present at the "Channel 2 Audio" terminal, LA(31)-1 → 1. When an audio signal is present in either or both of the inputs, LA-9 → 1 and Q4 is turned on. When an intensity display is not desired, Q4 is disabled by opening SW3

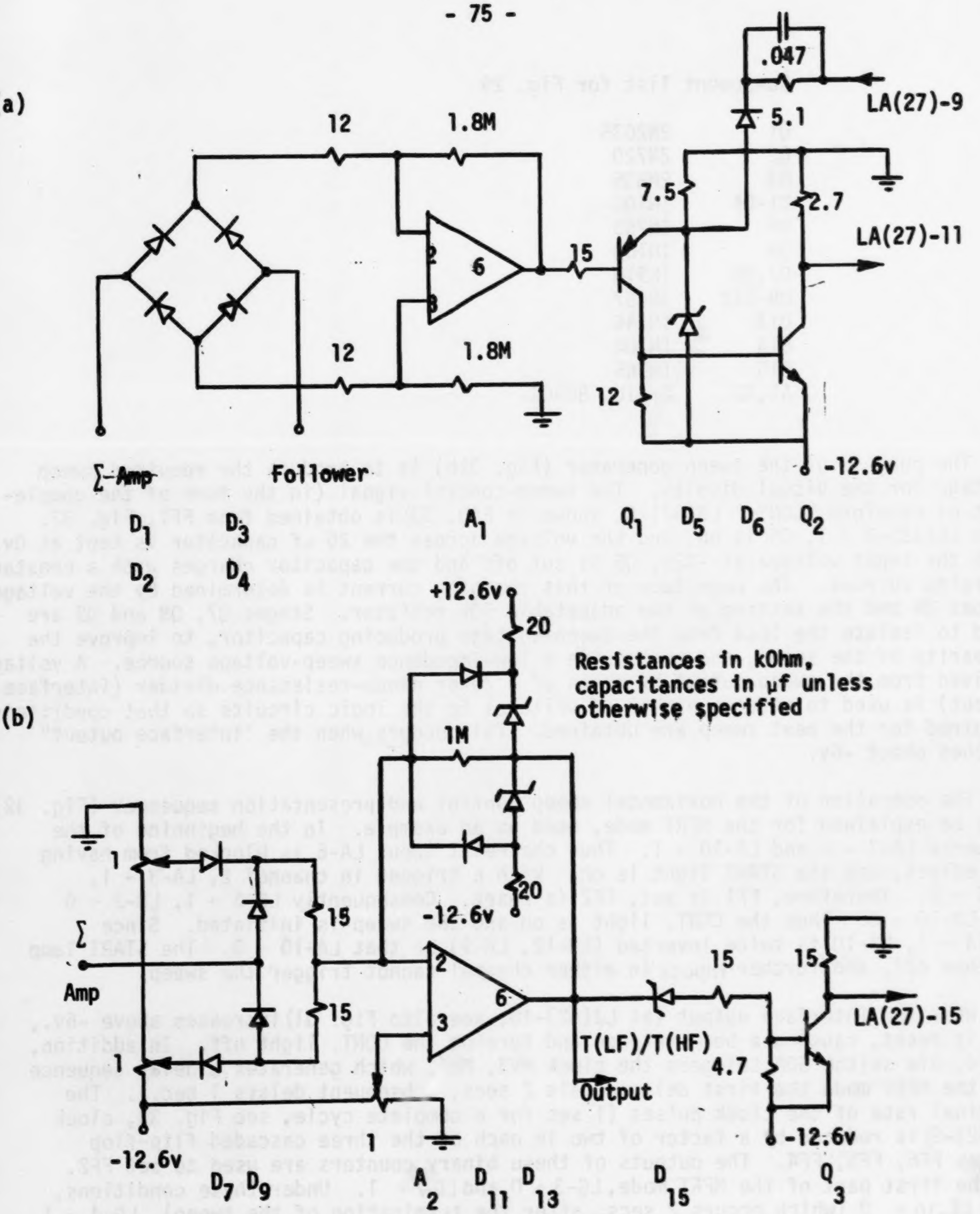

(a)
12
1.8M
2
6
3
12
1.8M
15
.047
5.1
LA(27)-9
7.5
2.7
LA(27)-11
12
-12.6v
∑-Amp
Follower
D_1
D_3
A_1
Q_1
D_5
D_6
Q_2
D_2
D_4
+12.6v
20
Resistances in kOhm, capacitances in μf unless otherwise specified
(b)
1M
1
15
20
-12.6v
∑
Amp
15
2
6
3
15
15
LA(27)-15
T(LF)/T(HF)
4.7
Output
1
-12.6v
-12.6v
D_7
D_9
A_2
D_{11}
D_{13}
D_{15}
Q_3
D_8
D_{10}
D_{12}
D_{14}

Fig. 29. (P-A); (a) ΔT Comparator, (b) T(LF)/T(HF) Comparator (Tri-Level Indicator)

Component list for Fig. 29

Q1	2N2635
Q2	2N720
Q3	2N835
D1-D4	IN100
D5	IN753
D6	IN100
D7,D8	IN910
D9-D12	IN457
D13	IN746
D14	IN704
D15	IN965
A1,A2	Amelco 809CE

The purpose of the sweep generator (Fig. 31b) is to produce the required sweep voltage for the visual display. The sweep-control signal (in the form of the complement of waveform "CONT." LB(32)-6, shown in Fig. 33) is obtained from FF1, Fig. 32. When LB(32)-2 → 1, Q5 is on, and the voltage across the 25 μf capacitor is kept at 0v. With the input voltage at -12v, Q5 is cut off and the capacitor charges with a constant charging current. The magnitude of this charging current is determined by the voltage across Q6 and the setting of the adjustable 50k resistor. Stages Q7, Q8 and Q9 are used to isolate the load from the sweep-voltage producing capacitor, to improve the linearity of the sweep, and to provide a low-impedance sweep-voltage source. A voltage derived from the sweep output by means of a Zener diode-resistance divider (interface output) is used to reset a number of voltages in the logic circuits so that conditions required for the next sweep are obtained. This occurs when the "interface output" reaches about -6v.

The operation of the horizontal sweep control and presentation sequencer (Fig. 32) will be explained for the MFRT mode, used as an example. In the beginning of the sequence LA-7 → 0 and LA-10 → 1. Thus channel 1 input LA-6 is blocked from having any effect, and the START light is on. With a trigger in channel 2, LA-3 → 1, LA-9 → 0. Therefore, FF1 is set, FF2 is reset. Consequently LB-6 → 1, LB-2 → 0 and LB-10 → 0. Thus the CONT. light is on and the sweep is initiated. Since LH-14 → 1, LB-10 is twice inverted (LH-12, LH-9) so that LA-10 → 0. The START lamp is then off, and further inputs in either channel cannot trigger the sweep.

When the interface output (at LJ(42)-10, see also Fig. 31) increases above -6v., FF1 is reset, causing a beam retrace and turning the CONT. light off. In addition, LJ-14, via switch SDA triggers the clock MV3, MV4, which generates a delay sequence (in the MFRT mode the first delay equals 2 secs, subsequent delays 1 sec.). The original rate of the clock pulses (1 sec for a complete cycle, see Fig. 33, clock LC(32)-9) is reduced by a factor of two in each of the three cascaded flip-flop stages FF6, FF5, FF4. The outputs of these binary counters are used to set FF2. In the first part of the MFRT mode, LG-3 → 0 and LG-7 → 1. Under these conditions, when LE-10 → 0 (which occurs 2 secs. after the termination of the sweep), LG-4 → 1 and LG-12 → 0. After passing switch SCB, LG-12 is differentiated to produce the setting trigger for FF2. With FF2 set, LB-10 → 1 which, via SBB and SW2, causes the START light to go on, through the mechanism explained above. In addition, since during this transition LB-10 → 1, while LF-14 → 0 and LH-3 → 1, LH-1 → 0. As a result, FF3 changes state, and LF-14 (which via switch SAA is fed to LA-7) → 1. The circuits are now ready to accept a new audio signal from either channel, for the

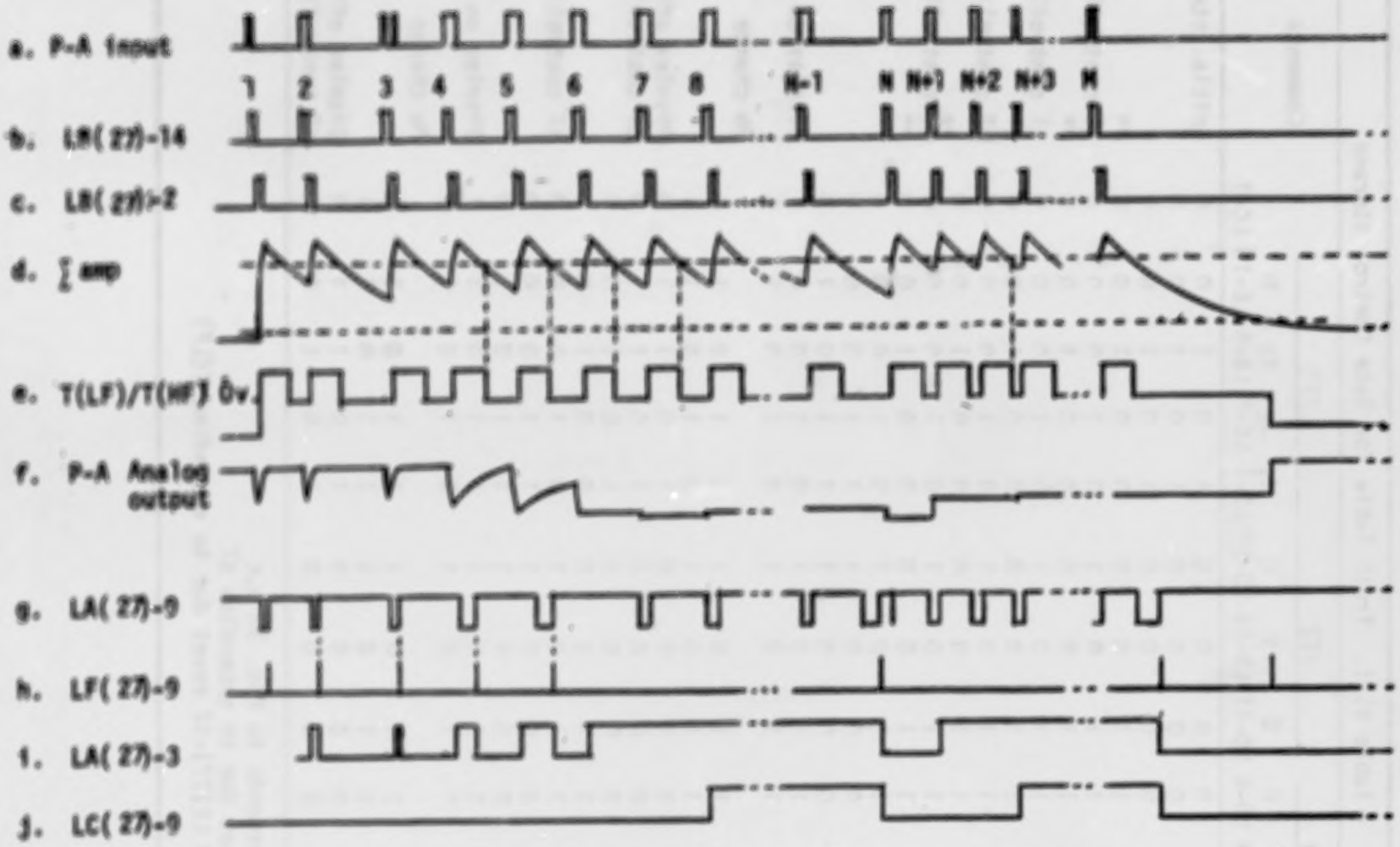

a. P-A input
1
2
3
4
5
6
7
8
N-1
N
N+1
N+2
N+3
M
b. LB(27)-14
c. LB(27)-2
d. Σ amp
e. T(LF)/T(HF) 0v
f. P-A Analog output
g. LA(27)-9
h. LF(27)-9
i. LA(27)-3
j. LC(27)-9

Fig. 30. Waveforms for P-A circuit.

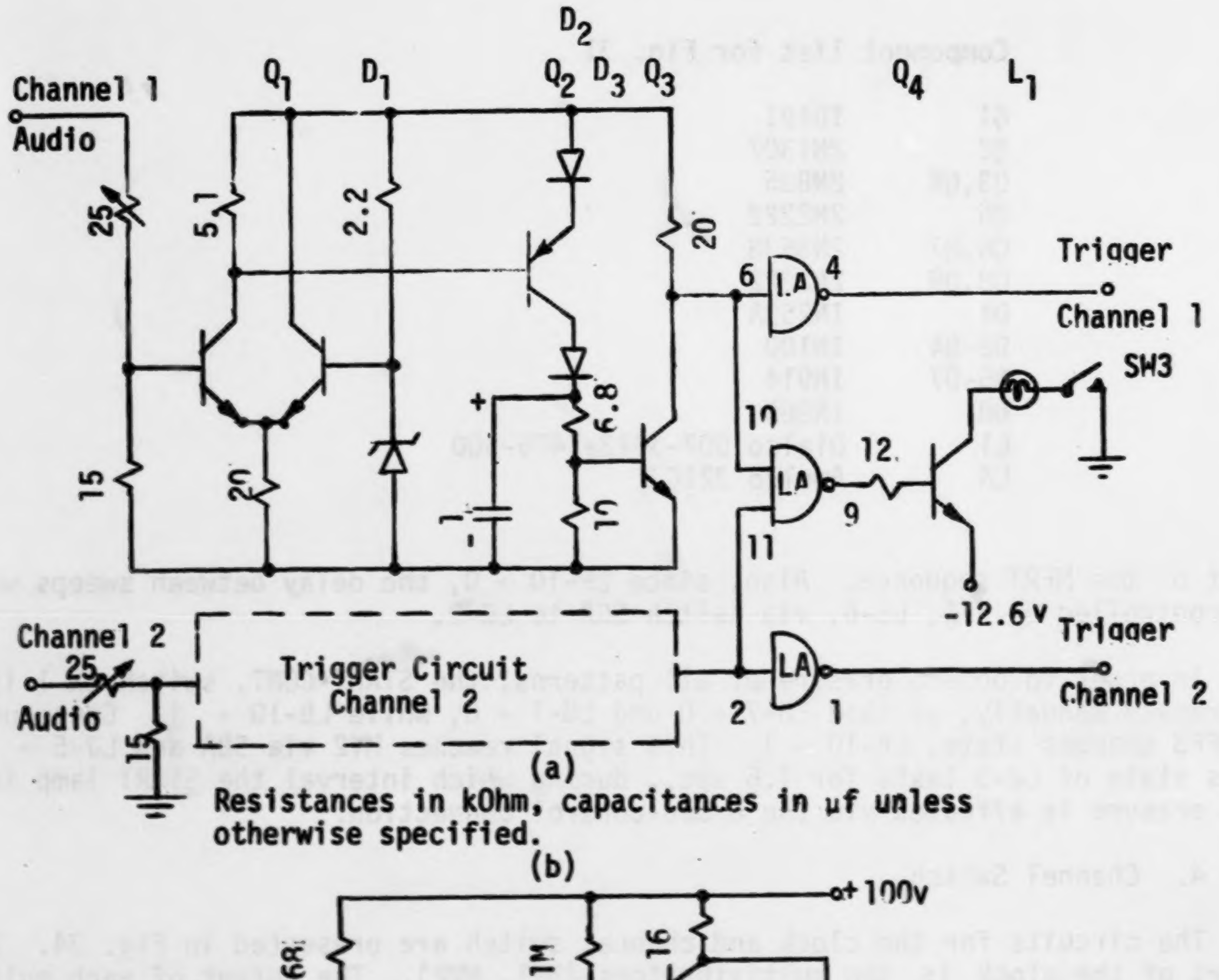
Table VIII. Truth Table for Gate Control Storage

Clock Pulse *	FF1			FF2			FF3					Comments
	J	K	Q	J	K	Q	J_1	J_2	K_1	Q		
	LD-5	LD-3	LD-6	LD-11	LD-13	LD-10	LE-1	LE-2	LE-5	LE-13	LC-9	
	0	1	0	0	0	0	1	0	1	0	0	Initial state
b 1	0	1	0	0	0	0	1	0	1	0	0	
c 1	1	1	0	0	0	0	1	0	1	0	0	
b 2	1	1	1	1	0	0	0	0	1	0	0	**
c 2	1	1	1	1	0	1	0	1	0	0	0	ΔT controlled
b 3	1	1	1	1	0	0	0	0	1	0	0	**
c 3	1	1	1	1	0	1	0	1	0	0	0	ΔT controlled
b 4	1	1	1	1	0	0	0	0	1	0	0	**
c 4	1	1	1	1	0	1	0	1	0	0	0	ΔT controlled
b 5	1	1	1	1	0	0	0	0	1	0	0	**
c 5	1	1	1	1	0	1	0	1	0	0	0	ΔT controlled
b 6	1	1	1	1	0	0	0	0	1	0	0	**
c 6	1	1	1	1	0	1	0	1	0	0	0	
b 7	1	1	0	0	0	1	1	1	0	0	0	
c 7	1	0	0	0	0	1	1	1	0	1	0	
b 8	1	0	1	1	0	1	0	1	0	1	1	Display on
c 8	1	0	1	1	0	1	0	1	0	1	1	
⋮												No change
b(N-1)	1	0	1	1	0	1	0	1	0	1	1	
c(N-1)	1	0	1	1	0	1	0	1	0	1	1	
**	1	0	0	0	0	0	1	0	1	1	0	Display off,
b N	1	0	0	0	0	0	1	0	1	1	0	ΔT controlled
c N	1	1	0	0	0	0	1	0	1	0	0	
b(N+1)	1	1	1	1	0	0	0	0	1	0	0	
c(N+1)	1	1	1	1	0	1	0	1	0	0	0	ΔT controlled
b(N+2)	1	1	0	0	0	1	1	1	0	0	0	
c(N+2)	1	0	0	0	0	1	1	1	0	1	0	
b(N+3)	1	0	1	1	0	1	1	1	0	1	1	Display on
c(N+3)	1	0	1	1	0	1	1	1	0	1	1	
⋮												No change
b M	1	0	1	1	0	1	1	1	0	1	1	
c M	1	0	1	1	0	1	1	1	0	1	1	
**	1	0	0	0	0	0	1	0	1	1	0	Display off,
***	0	1	0	0	0	0	1	0	1	0	0	ΔT controlled

* Timing corresponds to Fig. 30 b,c

** LF(27)-9 reset due to exceeding ΔT

*** LF(27)-9 and LE(27)-12 reset due to exceeding T(LF)


D2
Channel 1
Audio
Q1
D1
Q2
D3
Q3
Q4
L1
25
5.1
2.2
20
Trigger
6
LA
4
Channel 1
SW3
6.8
+
10
12
15
20
10
LA
9
11
-12.6 v
Trigger
Channel 2
25
Audio
15
Trigger Circuit
Channel 2
LA
2
1
Channel 2
(a)
(b)
+100v
68
1M
16
50
43
13
Sweep
Cont.
10
+
25
Sweep
Output
20
82
Interface
Output
-100v
2.7
-12.6v
D4
Q5
D5
D6
D7
Q6
Q7
Q8
Q9
D8

Resistances in kOhm, capacitances in μf unless otherwise specified.

Fig. 31. Sweep circuits (a) trigger generator (b) sweep generator.

Component list for Fig. 31

Q1	TD101
Q2	2N1307
Q3,Q4	2N835
Q5	2N2222
Q6,Q7	2N3638
Q8,Q9	2N2222
D1	IN753A
D2-D4	IN100
D5-D7	IN914
D8	IN965
L1	Dialco 507-3913-1475-600
LA	Amelco 321CJ

rest of the MFRT sequence. Also, since LF-10 → 0, the delay between sweeps will now be controlled by FF6, LE-6, via switch SCA to LG-2.

In order to obtain erasure of all patterns, the START-CONT. switch SW-1 is depressed manually, so that LH-7 → 0 and LH-1 → 0, while LB-10 → 1. Consequently, if FF3 changes state, LF-10 → 1. This signal reaches MV2 via SBA and LJ-5 → 0. This state of LJ-5 lasts for 1.6 sec., during which interval the START lamp is off and erasure is effected via the erase-control connection.

4. Channel Switch.

The circuits for the clock and channel switch are presented in Fig. 34. The heart of the clock is two multivibrators (MV1, MV2). The output of each multivibrator is connected to the input of the other one so that both are continuously triggered. In order to start the operation of the multivibrators initially, a single pulse is generated by the combination D1-Q1. The pulse is slightly delayed so that when itreaches the multivibrator circuits, the power in those circuits is already at its full value. The pulse repetition frequency of the pulses leaving the clock is 200 kHz. In order to produce the desired signal for channel 2, a summing amplifier A1 is used. The latter adds four different signals: (a) the voltage representing the logarithm of the fundamental frequency of the voice, coming from the P-A circuit (Fig. 27), (b) an offset voltage used to represent the habitual pitch level, (c) a blanking signal obtained from the P-A circuit, and (d) a fraction of the clock-output voltage. The blanking signal (c) deflects the beam outside of the screen area when a voiced sound is not present. The composite output signal of A1 is connected to the switch output by means of the field-effect transistor Q4. When the gate voltage is high, Q4 disconnects A1-6 from the switch output; otherwise, A1-2 is connected to the switch output. The process of developing a suitable gate voltage will be explained below. The operation of channel 1 is the same as the operation just described for channel 2, except that the output of the clock is not added to the other three voltages mentioned above: the net result is that while the limits of acceptability can be displayed in channel 2, only a single-line display results from channel 1. It is seen that the voltage resulting from channel 1 is connected to the same output through another field-effect transistor stage Q5. The necessary gate voltages for stages Q4 and Q5 are developed as follows: Each of the two states of the bistable multivibrator FF1 corresponds to one of the two channels; i.e., for one state, signal A1-6 is connected to the output, while for the other state, signal A2-6 is connected to the output. The state of LB is determined by the inputs

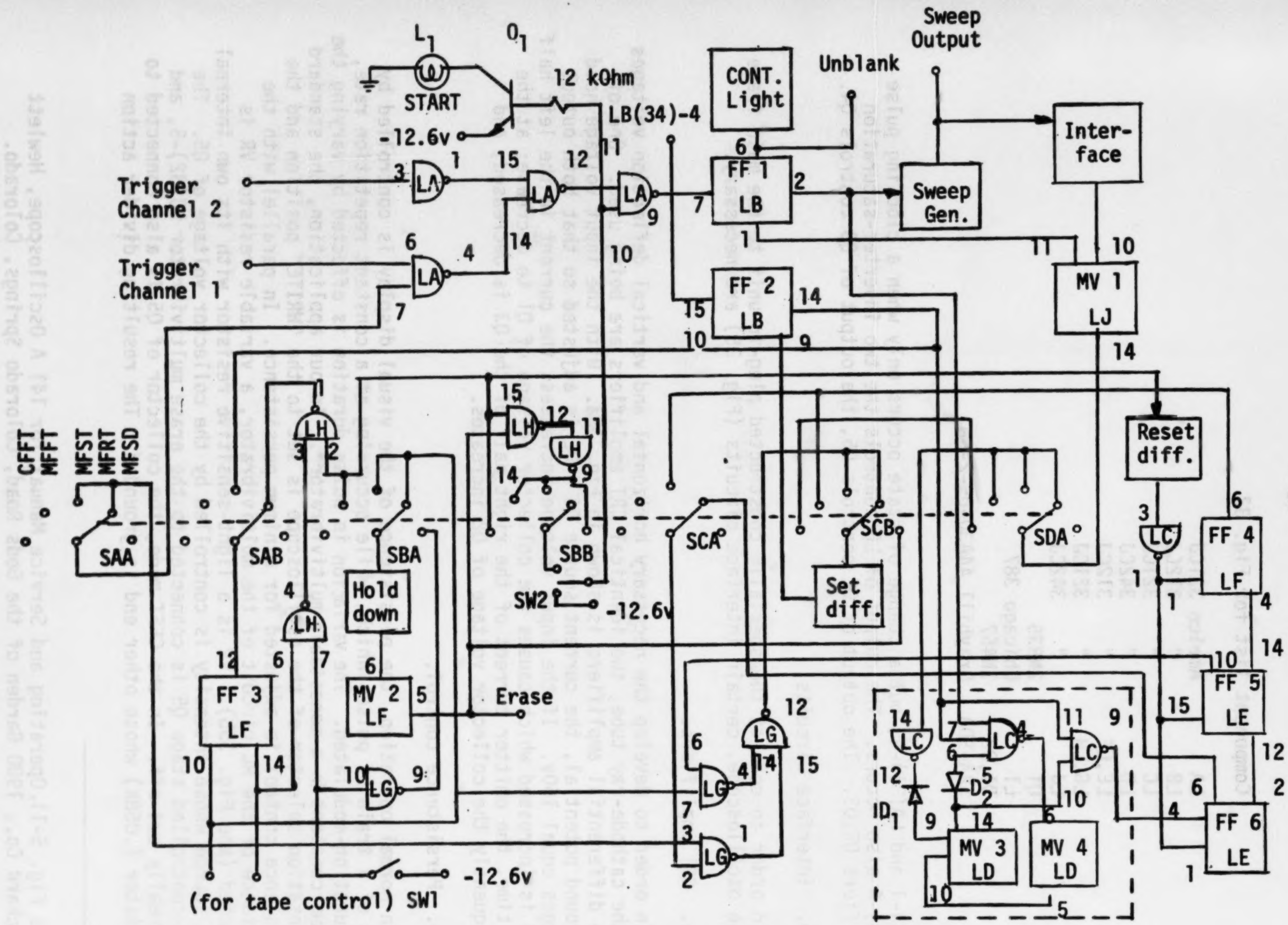

Sweep Output
Unblank
CONT. Light
Inter- face
Sweep Gen.
L1
START
O1
12 kOhm
LB(34)-4
-12.6v
Trigger Channel 2
Trigger Channel 1
LA
FF 1 LB
FF 2 LB
MV 1 LJ
Reset diff.
Set diff.
LC
FF 4 LF
FF 5 LE
FF 6 LE
MV 2 LF
MV 3 LD
MV 4 LD
FF 3 LF
Hold down
LH
LG
D1
D2
CFFT
MFFT
MFST
MFRT
MFSD
SAA
SAB
SBA
SBB
SCA
SCB
SDA
SW2
-12.6v
Erase
(for tape control) SW1
-12.6v

Fig. 32. Horizontal Sweep Control and Presentation Sequencer.

Component list for Fig. 32

LA	Amelco 321CJ
LB	" 312CJ
LC	" 321CJ
LD	" 342CJ
LE,LF	" 312CJ
LG,LH	" 321CJ
LJ	" 342CJ
Q1	2N835
L1	Chicago 387
D1,D2	IN457
SAA-SDA	Grayhill 44A30-05-2-6N

LA(31)-1 and LA(31)-4, but a change of state occurs only when a clocking pulse LA(34)-4 also occurs. The output of LB controls the two inverter-saturation amplifiers Q2,Q3. The output of Q2 controls Q5, the output of Q3 controls Q4.

5. Interface Circuits.

In order to connect the specially constructed plug-in unit to the main frame of the oscilloscope, certain interface circuits (Fig. 35) are necessary.

a. CRT amplifiers.

In order to develop the necessary horizontal and vertical deflection voltages for the cathode-ray tube, two identical CRT amplifiers are being used. One of these differential amplifiers is shown in Fig. 35a. With the input voltage held at ground potential, the current source Q4 - D2 is adjusted so that both output voltages equal 160v. If the input voltage increases, the current in the left half of Q3 is increased which causes the collector voltage of Q1 to decrease; at the same time, the emitter current of the right half of the Q3 is decreased, and consequently the collector voltage of Q2 increases.

b. Persistence control.

In normal operation, the persistence of the visual display is controlled by means of a train of pulses which, while occurring at a constant repetition rate, are duration-modulated. The variation in pulse duration is effected by varying the RC time constant in a monostable multivibrator*. In our application, the standard presentation selector of the oscilloscope is set to the "WRITE" position and the persistence control is adjusted for minimum persistence. In parallel with the resistance of the RC circuit of the multivibrator, a variable resistor VR is connected (see Fig. 35b). VR is a light-sensitive resistor with its own internal light source whose intensity is controlled by the collector voltage of Q5. The light-controlled stage Q5 is connected to the erase multivibrator LJ(32)-5, and is normally cut off. In the CFFT mode, the collector of Q5 is also connected to a resistor (.068k) whose other end is grounded. The resulting divider action

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* See Fig. 5-11, Operating and Service Manual for 141 A Oscilloscope, Hewlett Packard Co., 1900 Garden of the Gods Road, Colorado Springs, Colorado.

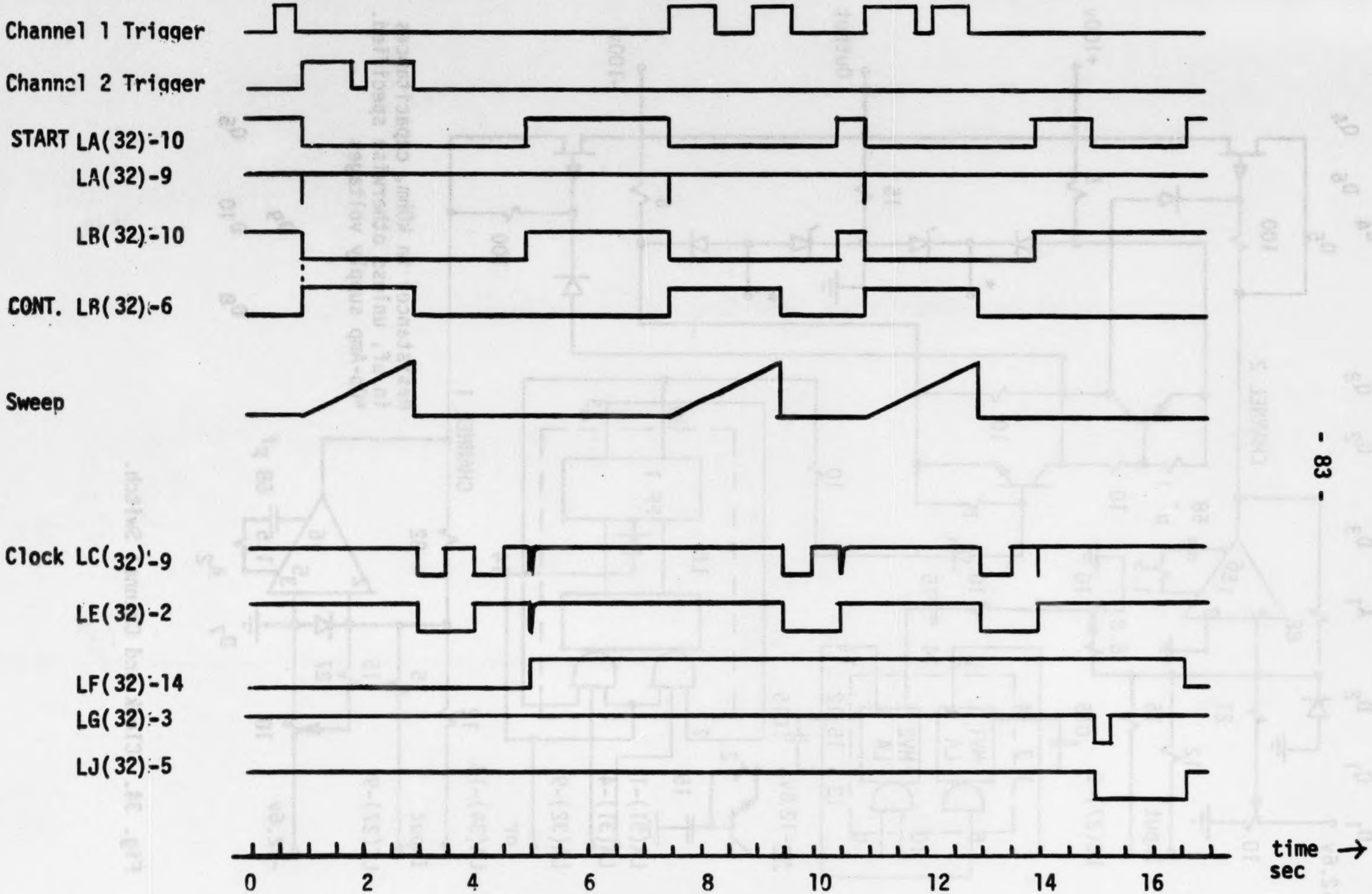
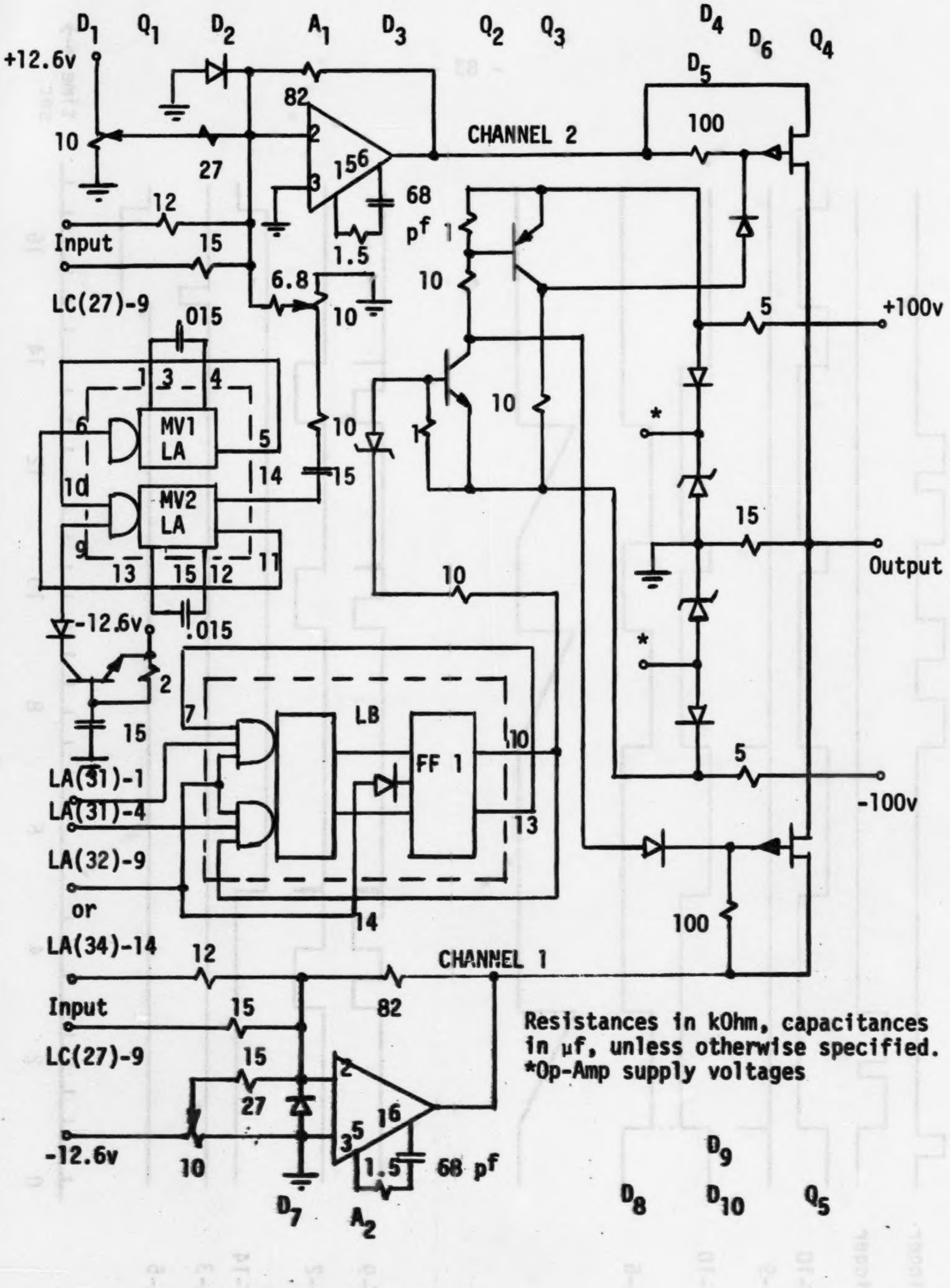

Channel 1 Trigger
Channel 2 Trigger
START LA(32)-10
LA(32)-9
LB(32)-10
CONT. LR(32)-6
Sweep
Clock LC(32)-9
LE(32)-2
LF(32)-14
LG(32)-3
LJ(32)-5
0
2
4
6
8
10
12
14
16
time →
sec

Fig. 33. Timing diagram for delay and sequencing logic in MFRT mode.


D_1
Q_1
D_2
A_1
D_3
Q_2
Q_3
D_4
D_6
Q_4
D_5
+12.6v
10
27
82
2
3
15
6
68
pf
1.5
CHANNEL 2
100
1
10
12
Input
15
LC(27)-9
6.8
10
.015
1
3
4
6
MV1
LA
5
10
14
15
1d
MV2
LA
9
13
15
12
11
.015
-12.6v
2
15
10
5
+100v
*
15
Output
*
5
-100v
7
LB
10
FF 1
13
14
LA(31)-1
LA(31)-4
LA(32)-9
or
LA(34)-14
12
Input
15
LC(27)-9
15
27
-12.6v
10
CHANNEL 1
82
100
2
16
3
5
1.5
68 pf
D_7
A_2
D_9
D_8
D_{10}
Q_5

Resistances in kOhm, capacitances in μf, unless otherwise specified.
*Op-Amp supply voltages

Fig. 34. Clock and Channel Switch.

Component list for Fig. 34

Q1,Q2	2N720
Q3	2N3645
Q4,Q5	2N2607
D1	IN100
D2	IN457
D3	IN704
D4	IN457
D5	IN965B
D6	IN100
D7	IN457
D8	IN100
D9	IN965B
D10	IN457
LA	Amelco 342CJ
LB	" 311CJ
A1,A2	" 809CE

between ground and the -12.6v source creates such a collector voltage that the persistence is kept at a moderate value. For other positions of the mode switch, the collector is connected to a grounded diode (D4) via the START-CONT. switch. Normally the switch SW1 is open and the input to Q5 controls the persistence of the display. When the erase multivibrator is in state 0, the input to Q5 decreases, the transistor Q5 is turned on, and the light intensity in VR is decreased. This sets the display persistence to its minimum value and the visual display is erased. A manual erasure of the visual pattern is effected by depressing the START-CONT. switch SW1.

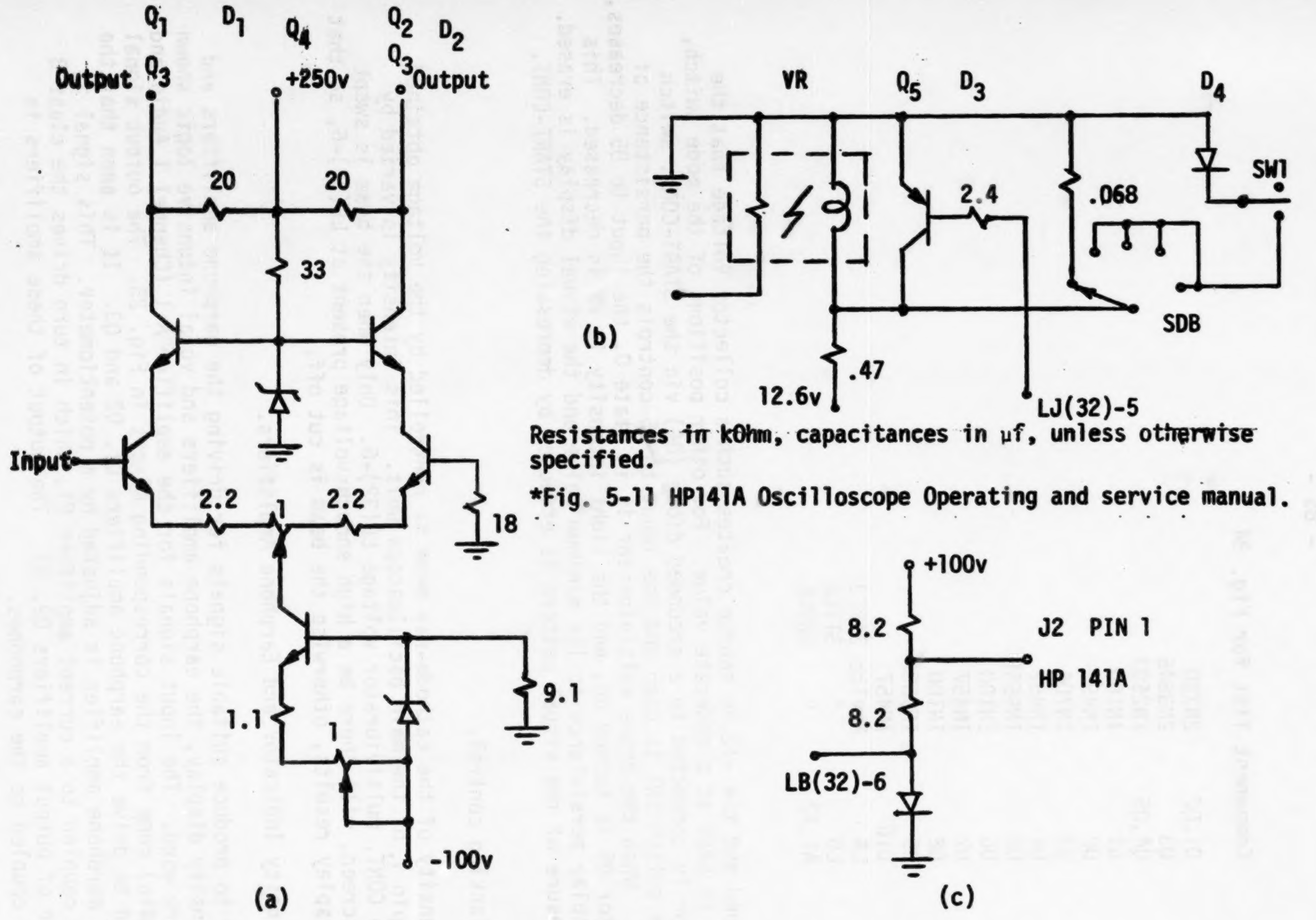
c. Unblanking control.

The intensity of the cathode-ray beam is controlled by the voltage obtained from jack 2 pin 1, of the main oscilloscope unit. This intensity is varied by means of the CONT. multivibrator voltage LB(32)-6. Only when the beam is swept across the screen, will there be a high enough voltage present at LB(32)-6, so that a visible display results, otherwise the beam is cut off.

6. Intensity Indicator and Earphone Amplifiers.

In order to produce suitable signals for driving the earphone amplifiers and for the intensity display, the earphone amplifiers and vocal intensive logic shown in Fig. 36 are used. The input signals for the amplifier A 1 (Channel 1 Audio and Channel 2 Audio) come from the corresponding mixers in Fig. 25. The output signal of A1 is used to drive the earphone amplifiers Q1, Q2 and Q3. It is seen that the gain of this earphone amplifier is adjusted by a potentiometer. This signal is capacitively coupled to a current amplifier Q1, which in turn drives the class B operated pair of output amplifiers Q2, Q3. The output of these amplifiers is capacitively coupled to the earphones.

The output of amplifier A1 also drives a rectifier-integrator circuit (D1). After amplification (A2), the signal is fed to two threshold circuits (Q4, A3). The first detector stage (Q4) detects a signal which is larger than the threshold


Q1
D1
Q4
Q2
D2
Output Q3
+250v
Q3 Output
20
20
33
Input
2.2
1
2.2
18
1.1
1
9.1
-100v
(a)
VR
Q5
D3
D4
SW1
2.4
.068
SDB
(b)
12.6v
.47
LJ(32)-5
+100v
8.2
J2 PIN 1
HP 141A
8.2
LB(32)-6
(c)

Resistances in kOhm, capacitances in µf, unless otherwise specified.

*Fig. 5-11 HP141A Oscilloscope Operating and service manual.

Fig. 35. Interface circuits between plug-in unit and main frame of oscilloscope, (a) CRT amplifiers, (b) persistence control, (c) unblanking control.

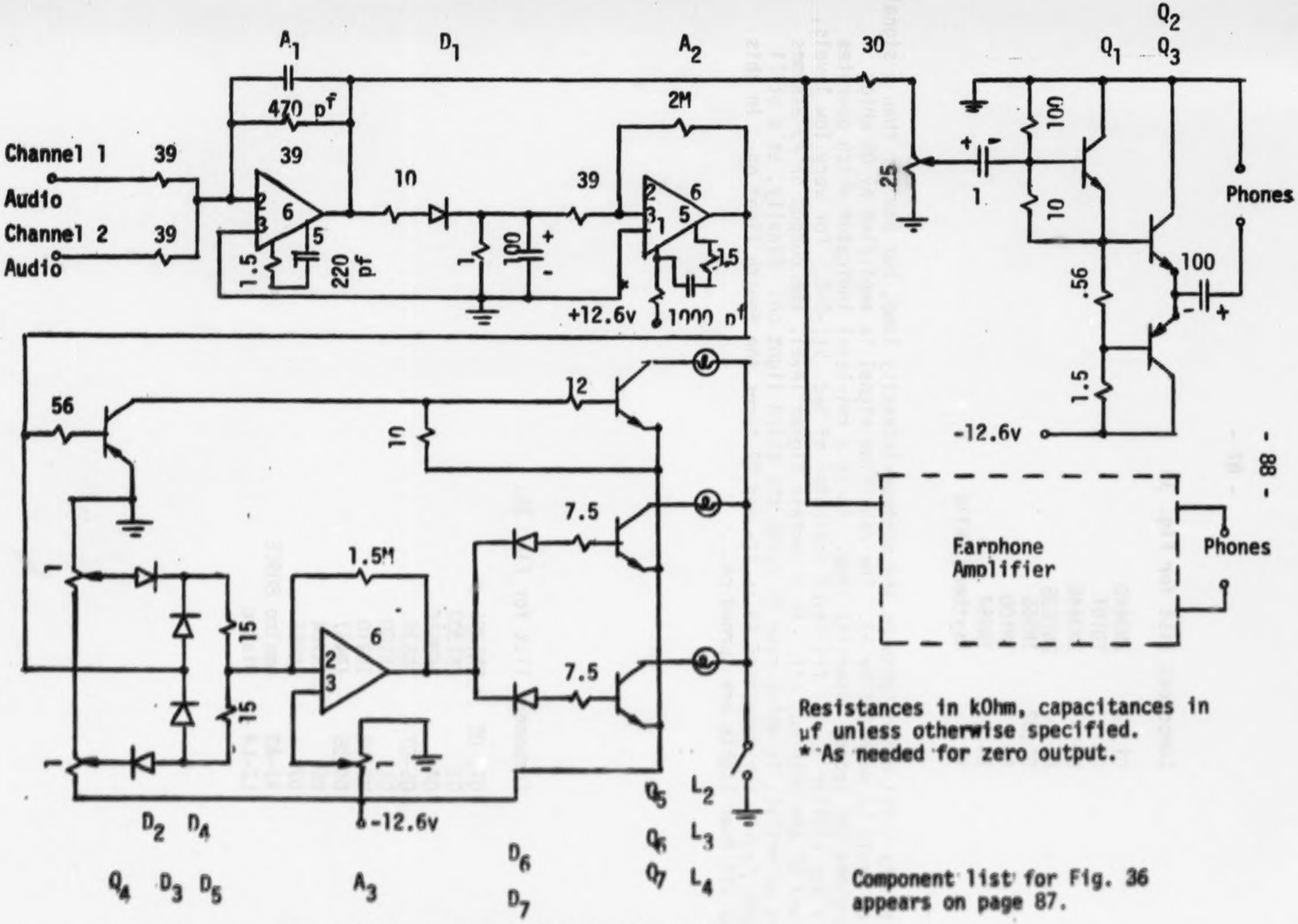
Component list for Fig. 35

Q1,Q2	2N3440
Q3	TD101
Q4	2N3440
Q5	2N2635
D1,D2	IN965
D3	IN100
D4	IN457
VR	Raytheon CK116

intensity level which turns on the minimum-intensity lamp, but smaller than a signal which would be detected by A3. The resulting signal is amplified by Q5 which energizes the second intensity lamp. A3 is a tri-level indicator which operates in a way similar to the tri-level indicator of Sec. VII-D-2. For very low levels, Q6 and Q7 are both cut off. At a certain higher level, the output of A3 assumes zero potential, in which case Q6 turns the third light on. Finally, at a still higher level, the output of A3 is 12v and Q7 turns the fourth light on. In this case all four lights are turned on.

Component list for Fig. 36.

Q1, Q2	2N1306
Q3	2N1307
Q4	2N3645
Q5-Q7	2N835
D1	IN100
D2,D3	IN910
D4,D5	IN457
D6	IN704
D7	IN965
A1-A3	Amelco 809CE
L2-L4	Dialco


A1
D1
A2
30
Q1
Q2
Q3
470 pf
39
2M
Channel 1
Audio
Channel 2
Audio
39
39
10
39
6
2
3
5
1.5
220 pf
1
100
+
-
+12.6v
1000 pf
1.5
25
1
100
10
.56
1.5
100
-12.6v
Phones
Phones
Earphone Amplifier
56
12
10
7.5
7.5
1.5M
15
15
-12.6v
D2
D4
Q4
D3
D5
A3
D6
D7
Q5
Q6
Q7
L2
L3
L4

Resistances in kOhm, capacitances in µf unless otherwise specified.
* As needed for zero output.

Component list for Fig. 36 appears on page 87.

Fig. 36. Earphone Amplifiers and Vocal Intensity Logic.

VIII. DISCUSSION

The results of the research reported here can best be viewed in terms of the interactions of an interprofessional team of researchers from the fields of electronics engineering, experimental psychology, speech pathology and the education of the deaf. The goals of the team during the course of the research were to develop equipment, teaching materials, and a training program which would assist deaf individuals, through providing instantaneous visual feedback, to improve their use of intonation patterns in speech. A secondary goal was to obtain data which would indicate whether deaf individuals benefited from the training program using visual feedback. This goal was considered to be secondary because there was evidence from several other studies that subjects improved while using visual feedback and that there was a critical need for the development of a training program for use with the IPPI equipment.

The constant interaction of the interprofessional team resulted in changes in equipment, teaching materials and program, and research design during the various phases of the research. While this approach created problems in carrying out a tight research design, it permitted continual improvements in equipment, training procedures and research design which would be more effective in the major goal of developing the best possible equipment and training program. Two members of the research team (Pronovost and Anderson) were also members of the team conducting research with the Voice Visualizer [32] under a U.S. Office of Education grant to Boston University, with engineering design and construction by Robert Lerner of the Massachusetts Institute of Technology, and experimental teaching by Linda Yenkin at the Boston School for the Deaf [36]. Experience with the Voice Visualizer research influenced the activities of the Northeastern University team on the IPPI projects.

In the initial phases of each stage of the research, there was a tendency to design the training program to fit the capabilities of the equipment. Thus, the original study with normally-hearing adults [8,9] used sustained tones because these could be displayed easily on the original experimental model. During the study with deaf adults, it was desired to compare the responses of deaf adults with normally-hearing adults; therefore the same stimulus-response items were used in the study with the deaf adults. However, it was also desired that intonation patterns of spoken phrases be displayed for self-monitoring. Improvements in circuit design and stability made this possible during the adult study. It was also felt that deaf adults would have difficulty matching a single-line stimulus pattern and become frustrated by failure. Therefore, a system of presenting stimulus tones (upper and lower) as limits, with a response being correct if it occurred between the two limiting lines (see Fig. 15, Ch. V) was developed. A control permitted narrowing of limits from two tones to one tone to a single line. Unfortunately, the circuitry at this stage of the research did not permit use of limits for spoken phrasal stimuli. Research design of the children's study did not include sustained tones; therefore, the limit-type stimuli were not used. However, the desirability of a dual trace for shaping behavior was recognized and circuits have been developed to permit use of limits with spoken phrases in Model III (see Ch. VII).

In designing a program to fit the capabilities of the equipment, the researchers used spoken phrases whose linguistic structures involved intonation patterns identical with those which could be displayed by patterns of sustained tones, thus encouraging transfer from one type of drill to another. This procedure of basing the sequence of the training program on related linguistic units was used through the research with both deaf adults and deaf children.

Problems were encountered in obtaining data that could be analyzed and interpreted meaningfully. Some of these problems were related to the equipment, some to the subjects, and some to the inadequacy of information on the most desirable training program to be used experimentally.

New methods of data gathering were required for deaf adults and deaf children. The deaf adults were unable to meet criteria on a particular task as the normally hearing adults had done. The study with normally hearing adults used a mathematical procedure for determining accuracy of matching stimulus patterns. This procedure proved to be more precise and laborious than required by the questions being asked in the research. Therefore, new approaches to data were used. With the deaf adults, a system of tabulating number of trials and successful responses to each learning task was devised. However, the variability among subjects to the tasks precluded any statistical treatment of the data, so that only empirical interpretations could be made (see sample data in Appendix C). Listener judgments of pre- and post-test tape recordings were used to determine improvements occurring during the training programs with the equipment. The failure of the data to demonstrate significant improvements in most deaf adult subjects may be due in part to the fact that the test material involved spoken phrases which not only were not practiced during training, but also required speaking skills for which training was provided only briefly at the end of the program. Thus, the pre- and post-test comparison anticipated greater improvement than the training program and amount of time spent with the equipment could be expected to achieve. While the listener judgments of pre- and post-tests was maintained as the data-analysis procedure for the deaf children, the tasks included in the tests were directly related to the learning tasks of each phase of the program. In addition, test tape-recordings were obtained for each two-week period of the eight weeks' training program. The results of this approach, as shown in Ch. VI, Fig. 19, indicate that it is a useful method of data analysis which reveals the improvements made according to the time in the training program when the greatest improvements occur for specific tasks.

A major problem throughout the research was the devising of learning tasks and a sequence of presentation of these tasks in an experimental program. Data was not available on the sequence in which tasks, capable of being monitored on the IPPI, should be presented. Therefore, the sequence was based on assumptions that learning should proceed from relatively easy non-speech vocalizations to more complex patterns including spoken phrases. As the experimental program devised for deaf adults continued, it became apparent that ability on one task was not necessarily related to or dependent upon ability on another task. It was also apparent that tasks involving speech -- i.e., words and phrases, -- were easier for the deaf adults than the tasks requiring pitch control of sustained phonations. Some deaf adults had little success with the sustained-tone tasks which all normally-hearing subjects had learned easily. Thus, the study with deaf adults indicated that training should begin with speech-like tasks. Experience with the deaf adults also indicated that control of intonation patterns was dependent upon the presence of appropriate rhythm patterns of speech. (The importance of rhythm patterns had also been noted from a retrospective interpretation of the results of the Voice Visualizer study [32]). Therefore, the learning tasks and teaching sequence for the children's study were developed so as to incorporate the conclusions of previous studies. Naturally, the change in experimental design precluded any direct comparison with the data of previous studies. However, the results of data analyses for the children clearly indicated that progress had been made in identifying learning tasks and learning sequences which were more meaningful and appropriate for deaf children.

In both the IPPI children's study and the Voice Visualizer children's study, listeners judged the greatest improvements to have occurred in the early phases of each program, with less improvement occurring as the training continued. It was observed that children became less motivated as the program continued. It appears that the tasks devised can be learned quickly by most subjects and that an expanded training program with many new and more complex speaking tasks is required.

During the research with the IPPI, the researcher administering the listening panels' judgments of the deaf children's group inferred that one reason for less improvement to be judged in later stages of the program may be that early, rapid improvements in rhythm, and later pitch, were not then followed by improvements in articulation and that, without changes in articulation, further improvements in the total speech pattern would not be so judged by the listeners. Likewise, the researchers of the Voice Visualizer project noted, in retrospect, that the "advanced speakers" group, which improved in intelligibility, while the "poor speakers" groups did not, had acquired more "natural" rhythm and intonation patterns prior to their learning in articulation. The inference from the studies with the IPPI and the Voice Visualizer is that combined training is needed on all aspects of voice and speech if intelligibility is to be improved significantly.

One of the problems in this research was that of the criteria for selecting subjects. The normally-hearing subjects in the first study were selected according to criteria for successful learning of specific tasks. Criteria for volunteer deaf adults was limited to the fact they were volunteers obtained from known groups of deaf adults. Audiometric tests confirmed that they were all profoundly deaf. However, case studies of each subject did not reveal any information that could appear to be interpreted as related to the subject's response to the training program. In the Voice Visualizer study [32], two groups of speakers were chosen according to specific criteria -- audiometric examination indicating profound deafness, intelligence within normal limits, "poor" articulation of vowels or consonants or both, and absence of behavior problem in the school situation. However, with these criteria there was variation in the amount of improvement during the training program. Case studies indicated a range of home environmental conditions which may have influenced the responses to the program, but these are difficult to analyze. Another aspect of subject selection considered was visual perception, in the belief that it might be related to a subject's ability to use visual feedback information. Selection of tests of visual perception presented a problem. No tests could be found for measuring ability to follow changing visual patterns. For the deaf adults the Witkin Imbedded Figure Test [43] was used. No relationship could be found between the results of the Witkin test and improvement during the experimental training program. For the children in the Voice Visualizer study [32], the Frostig Developmental Test of Visual Perception [13] and the Ayers Space Test [2] were used. Results of these two tests did not correlate with each other, nor did scores on these tests appear related to the amount of improvement made by individual children. However, in a pre-training program, all Voice Visualizer children demonstrated ability to match the visual patterns on the oscilloscope screen with photographs of the patterns. It appears that existing tests of visual perception are not useful in relation to the tasks of visual monitoring of speech patterns, although one would suspect that children with poor visual perception as measured by existing tests would have difficulty using visual feedback information.

Since previously used criteria did not seem to be related to a subject's response to the training with a visual feedback unit, it was decided to limit selection of deaf children for the IPPI research to those children at the Horace

Mann School for the Deaf who were designated by the teachers as children who might benefit from, and were emotionally suited to, the experimental program planned for them. Although all children made improvements during some phase of the program, there was variability in their responses and amount of improvement. It is evident that more attention must be given to establishing criteria for subject selection in future research.

Despite the problems mentioned above, the investigators feel that their data, together with data of other investigators (see Ch. III) have demonstrated that visual feedback systems for self-monitoring of speech by the deaf do facilitate the learning of specific vocal tasks, such as rhythm and intonation. They are also encouraged by the data from the children's IPPI study, and the Voice Visualizer study, indicating progress in identified useful learning tasks and training sequences, especially for early stages of training. The data indicated that the tasks were learned in the hypothesized sequence, but in a much shorter period of time. It is apparent that more research is required on the more complex tasks to be included in later stages of a training program.

An important aspect of the research was the continual refinement of electronic circuits, which resulted in a more compact instrument which can be readily transported and used in classrooms of schools for the deaf. In addition, many new features were designed into the final Model III (see Ch. VII) as a result of the experimental programs with deaf subjects and the continual interaction of members of the inter-professional research team. One feature added to Model III was an Intensity Indicator, with lights indicating various levels of vocal intensity. This aspect of the unit was included to provide training in vocal intensity, if required, since intonation patterns must be superimposed on a voice produced with adequate vocal intensity, and it had been noted that some adults and children needed pre-training in vocal intensity before they could profitably use Model II of the IPPI. The new circuits were also designed to provide more stable responses to the rhythm patterns of speech. Design changes in Model II included a two-channel input so that the teacher and the student could use separate microphones, permitting the teacher to provide a stimulus pattern and the student to imitate the pattern immediately. A further improvement in Model III provides a combination microphone-earphone for both teacher and student to eliminate handling the microphone and provide a constant distance from mouth to microphone, for more consistent vocal signals to the pitch detector circuits. When differences in pitch levels from subject to subject and between subject and teacher were found to be distractions in the adult study, control circuits were introduced into each channel so that the teacher could adjust her pattern and the subject's to the same level, in order to avoid confusion when concentrating on intonation patterns. If a subject's pitch level was too high or too low, the teacher could make adjustments to permit teaching of optimal pitch level prior to teaching rhythm and intonation. During the adults' and children's studies, it also became apparent that different combinations of teacher-student responses were required. In addition, it was desired to have automatic erasure of stimulus and response patterns after brief periods of exposure. Therefore, a variety of display and erasure modes were designed into the equipment, and selected by a mode switch. In Model III, the teacher or student can select among modes which permit simultaneous display of teacher and pupil patterns, display of several student responses for one stimulus pattern, with either automatic erasing of both patterns after a 2 or 4 sec interval, or display for as long as desired by using a manual erase switch instead of automatic erasing. Although the circuit providing stimulus limits for sustained tones could not be used with speech patterns for the children's study, this feature was deemed desirable in Model III; the circuit design now permits an optional external control to provide dual stimulus-pattern traces as limits within which the student's response should occur. The control permits gradual narrowing of the dual trace to a single line as a student improves in vocal pitch control.

As a consequence of this research with an interprofessional team, in which both equipment and training programs were constantly refined, it is apparent that deaf individuals do benefit from training with a visual feedback system for self-monitoring of speech and voice. Useful equipment has been constructed with some features which have not been tried experimentally.

Information on the details of a desirable training program still needs to be obtained from further research. In all studies, there was a lack of continuous improvement by subjects throughout the program, which the investigators feel is due to weaknesses in the training programs used. New and additional program features need to be devised and evaluated, especially the features of a comprehensive speech-training program for all parameters of speech and voice, capable of display on visual feedback equipment. There is also the need to devise and evaluate a program for use of self-instructional features now possible with the newly completed equipment.

With respect to new equipment which might be useful for more extensive training by means of visual patterns, a personal pitch/intensity display, possibly using a regular home TV receiver or some other inexpensive visual display instead of the storage oscilloscope used in the present equipment, should be developed. The desire for more extensive use of such equipment in their own houses has been expressed by a number of the adult deaf subjects.

IX. SUMMARY AND CONCLUSIONS

A. Summary.

This study was concerned with the use of the Instantaneous Pitch-Period Indicator (IPPI) with deaf children and adults as a unit for visual self-monitoring of intonation patterns of speech. The methodology of this two-year study emphasized the interactions of an interprofessional team including researchers with training and experience in electronics, engineering, education of the deaf, speech pathology, and experimental psychology. The major phases of the project were engineering design and modification of equipment, development and modification of teaching programs, and testing of specific teaching programs with deaf children and adults. Initial programs were devised to fit the capabilities of the equipment at a particular time. Trial programs resulted in modifications of both equipment and program, with engineering modifications related to programs being redesigned to meet the needs of deaf subjects as indicated by the data of each phase of the research. The focus of the various stages of the study was to arrive at a feasible unit of equipment, accompanied by a training program for its use in teaching rhythm and intonation patterns to deaf subjects.

Following initial modifications of the equipment from Model I used with normally-hearing adults, a study was conducted with nine deaf adults over a period of several months. Tape recordings were made before and after the training program and improvements measured by listener judgment comparisons of the two test tapes. Clinical observations were also made of the subjects' responses to the training. Improvements were not as great as expected.

Results of the study with deaf adults were used in modifying both equipment and teaching programs for research with deaf children. Fourteen deaf children participated twice weekly for eight weeks. Tape recordings of the children's performance on imitative vocal pitch tasks were made at the beginning of the program and at the end of every two weeks of training. Listeners' judgments were obtained for comparisons of the children's use of pitch between tests 1 and 2, 2 and 3, and 3 and 5. The data were analyzed to determine the learning tasks showing the greatest improvement and the period of time in the training program when the greatest improvements occurred.

In the latter stages of the project, a new portable model of the Instantaneous Pitch-period Indicator (IPPI-AID) was constructed. Engineering refinements, both electronic and mechanical design, were incorporated into the IPPI-AID. New features included a series of lights to indicate vocal-intensity levels, more precise responses to rhythm and pitch changes, controls for adjusting the patterns of both stimulus and response channels, inclusion of several modes of pattern triggering, and automatic erasure of stored patterns. Headsets permit simultaneous auditory and visual feedback. A mirror above the unit permits visual communication between the teacher and student while watching the oscilloscope screen.

B. Conclusions.

From the objective data and clinical impressions of the researchers, the following conclusions can be drawn:

1. A portable Instantaneous Pitch-period Indicator: Amplitude, Intonation, Duration (IPPI-AID), capable of providing instantaneous visual and auditory feedback for self-monitoring of vocal intensity, rhythm and intonation patterns of speech, and capable of operation by teachers and deaf children, has been developed.

2. Listeners judged that significant improvements occurred in certain aspects of rhythm and intonation patterns during the experimental training program with deaf children.

3. Improvements tended to occur rapidly in the early stages of a training program and were less noticeable as the program progressed. Subjects became less motivated during late stages of training.

4. Judged improvements in selected aspects of voice usage emphasized in the training program were not necessarily accompanied by changes in the overall intelligibility of the deaf individual's speech.

5. While each population of subjects used a revised training program based on the results of previous studies, the results thus far did not yield sufficient data for definitive conclusions concerning the most desirable learning tasks, nor the sequence of these tasks, to be included in a training program.

C. Recommendations.

As a result of the research experience and findings in the studies now completed, the investigators have identified the following needs for further study:

1. The need to conduct a demonstration project using the IPPI (AID) in classrooms of deaf children, correlating the training with classroom instructional materials and procedures.

2. The need to concentrate on a total speech-improvement program, according to the voice and speech problems revealed by each individual subject.

3. The need to combine newly-designed features and equipment into a Visible Speech System with other equipment, such as the Voice Visualizer, to provide a comprehensive speech training program.

4. The need to obtain more data on the learning of rhythm and intonation patterns by normally-hearing and deaf children as a basis for experimental development of a comprehensive speech-training program for the deaf.

5. The need to use individual-subject research as a procedure for determining the responses of subjects with varying levels of speech proficiency to a training program.

6. The need to explore the potential for self-instructional use of the equipment through the use of stimulus-tape recordings and equipment developed for home use.*

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* Considering the possibility of future self-instructional use of the IPPI-AID in the future, the appropriate controls were made accessible in the equipment described in Ch. VII; in particular, in Fig. 32, the output of FF3 can be used to start and stop the tape recorder which supplies the stimulus pattern.

7. The need to conduct controlled research to compare the relative merits of visual feedback with combined auditory and visual feedback from the IPPI-AID.

8. The need to conduct research into the transfer of learning from the visual feedback situation to spontaneous speech instructions without visual feedback.

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APPENDIX A

Case Study Information and Audiograms for Deaf Adults

TABLE A1. Audiogram Symbols

O air conduction - right ear

X air conduction - left ear

> bone conduction - right ear

< bone conduction - left ear

[bone conduction (masked) - right ear

] bone conduction (masked) - left ear

↓ through or below a symbol means no response

Subject 1-A, Female, age 35.

Home Environment and Occupation

Miss A lives alone and is employed as a medical research assistant.

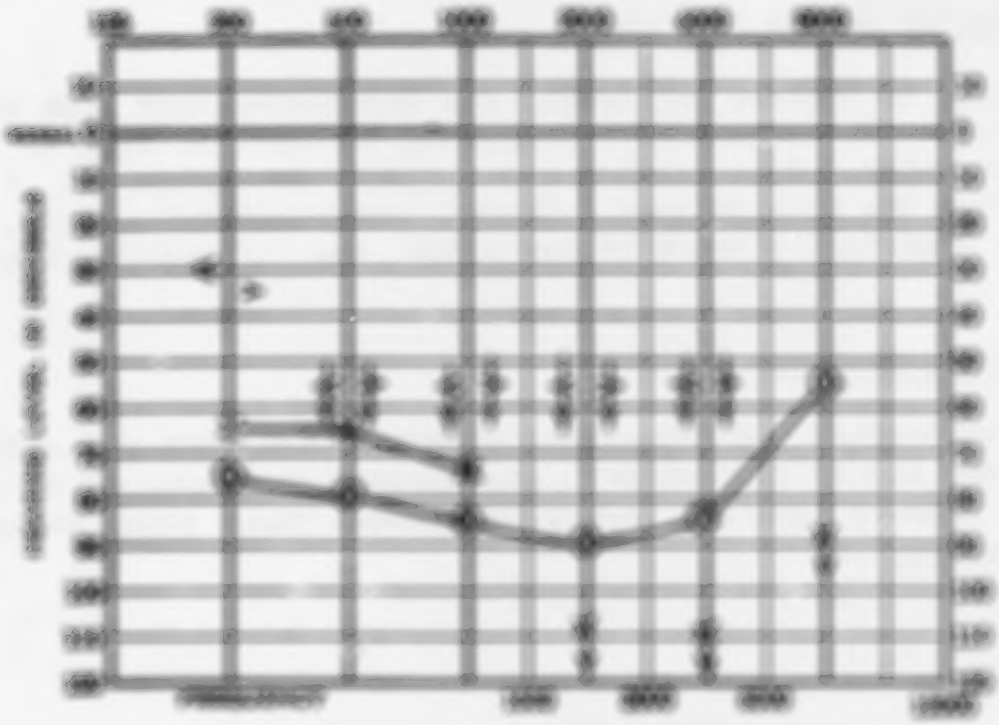

Fig. A-1. Audiogram for subject 1-A.

History of Deafness

Miss A was born deaf. The etiology of her deafness is unknown.

Visual Perception

Miss A's total time score on the Witkin Imbedded Figures Test was 16'. Her group rank was 5.

Education

Miss A attended two elementary schools for the deaf separated by two years at a school for the normally hearing. Subsequently, she attended a regular high school and graduated from Colby Jr. College.

Communicative Behavior

Miss A has always communicated through speech and lipreading. She has no knowledge of dactylology.

Social Behavior

Miss A is disturbed by the fact that she does not associate with the manual* deaf population. However, she has such an aversion for the use of signs that she cannot convince herself to learn and use them. Miss A participates in numerous outdoor sports with the oral deaf and hearing populations.

Initial Observations of Speech and Voice

Miss A's speech was highly intelligible and her lipreading ability was excellent. Her habitual pitch level was natural and she was able to produce some inflectional changes. Her speech rhythm was good. A slight tremor was apparent in her voice.

Observations of Behavior During Sessions

Miss A was anxious to improve her speech and approached each task with a great deal of determination. She succeeded in producing inflections only by increasing the intensity of her voice. As a result, she acquired an unpleasant, strained quality while uttering the task phrases. During conversational speech, however, when Miss A was not consciously aware of her pitch, the inflections she made were more natural.

Observations of Changes in Vocal Behavior

Miss A learned to produce the intonation patterns both with and without feedback from [illegible]. Toward the end of the project, she learned to produce a fairly good rising inflection. However, she was unable to achieve these pitch changes without increasing her intensity.

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* The term manual deaf refers to deaf adults who communicate by sign language.

Subject I-B, Female, age 34

Home Environment and Occupation

Miss B lives alone. She has had numerous other jobs prior to her current employment as a medical laboratory technician.

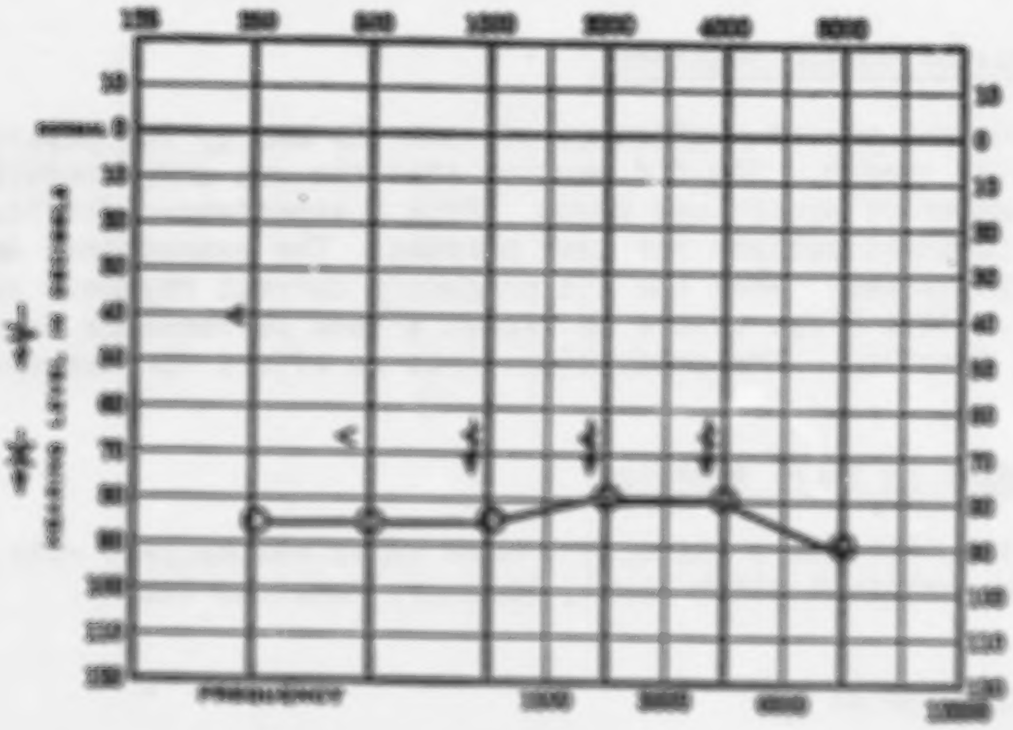


Fig. A-2. Audiogram for subject I-B.

History of Deafness

Miss B acquired deafness at the age of five as a result of spinal meningitis.

Visual Perception

Miss B had a total time score of 39" 30" on the Witkin Imbedded Figure Test. She had the largest time score of all subjects; her group rank was 9.

Education

Miss B attended three regular elementary schools, received a diploma from a regular high school, and has taken courses at several colleges.

Communicative Behavior

Miss B has always used speech and lipreading in order to communicate. She does have a knowledge of dactylology which she uses in communicating with her manual deaf friends.

Social Behavior

Miss B is a very thoughtful individual. Frequently she has offered her assistance to deaf people with personal or vocational problems. She is active in hiking and church work and participates with both the deaf and hearing populations.

Initial Observations of Speech and Voice

Miss B's habitual pitch level was lower than average. Inflection was practically absent. Her rate of speaking was slow. Articulation and lipreading abilities were good.

Observations of Behavior During Sessions

Miss B was a pleasant person who seemed to lack the energy for physical exertion of any kind, including speech. She did mention that she was under medical care and had been taking a number of prescribed drugs. Miss B experienced difficulty in producing the correct rhythmic pattern for task phrases. The expressions were uttered in a slow and mechanical manner. When she did produce a correct rhythmic pattern, her inflection was good. Miss B was unable to repeat a good performance from one session to the next without practice. The productions were an effort for her and she tired easily.

Observations of Changes in Vocal Behavior

Miss B learned to utter the phrases at a more rapid and natural rate, and with good inflection. Her habitual pitch level, however, remained low.

Subject I-C, Male, age 44

Home Environment and Occupation

Mr. C lives with his deaf wife and three hearing children in an upper middle class subur . He is employed as a dental technician.

History of Deafness

Mr. C acquired deafness in infancy as a result of spinal meningitis.

Visual Perception

Mr. C's total time score on the Witkin Imbedded Figures Test was 13' 25". His group rank was 4.

Education

Mr. C attended two elementary schools for the deaf and a high school for the normally hearing.

Communicative Behavior

Mr. C has always used speech and lipreading in order to communicate. He has no knowledge of dactylology.

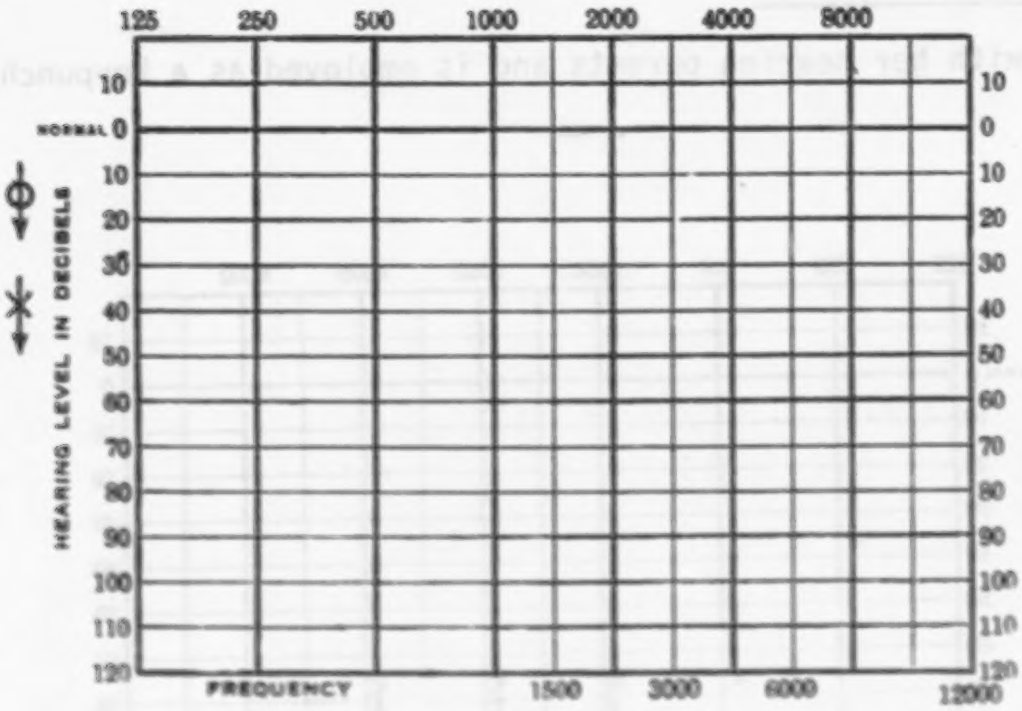


Fig. A-3. Audiogram for subject I-C.

Social Behavior

Mr. C is a happy, gregarious person. He spends most of his leisure time socializing with hearing people. He explained that he does not have much in common with the majority of the deaf population whose vocabulary and interests he considers juvenile.

Initial Observations of Speech and Voice

Mr. C's articulation of sounds was generally accurate. His speech intelligibility, however, was only fair due to an uncontrollable fluctuation of pitch between the falsetto and normal range. His speech rhythm was good.

Observation of Behavior During Sessions

Mr. C was very friendly and enjoyed talking to the research teacher. During conversations he repeated over and over any word that was not understood by the teacher. His patience and perserverence were unlimited. Mr. C considered the speech program a challenge and was eager to succeed in it. He practiced each pitch task until he produced a satisfactory response, once making 100 attempts at an expression which gave him trouble.

Observations of Changes in Vocal Behavior

Mr. C learned to control his habitual pitch level during the production of previously practiced tasks. In addition, he learned to produce falling and rising inflections, as well as appropriate intonation patterns for words and expressions which he had practiced. These accomplishments prevailed during the delayed-feedback phase of the program with the IPPI.

Subject I-D, Female, age 21

Home Environment and Occupation

Miss D lives with her hearing parents and is employed as a keypunch operator.

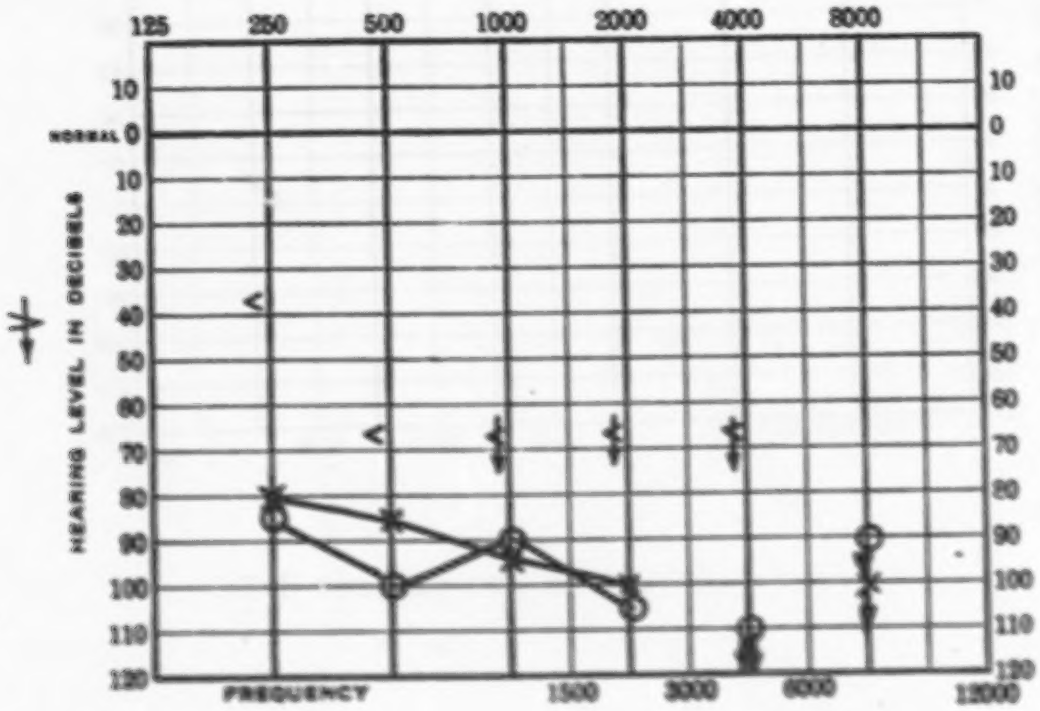


Fig. A-4. Audiogram for subject I-D.

History of Deafness

Miss D was born deaf. The etiology of her hearing loss is unknown.

Visual Perception

Miss D had a total time score of 12' 15" on the Witkin Imbedded Figures Test. Her group rank was 3.

Education

Miss D attended two elementary schools for the deaf and the Vocational High School at American School for the Deaf.

Communicative Behavior

Miss D communicates primarily through sign language. Her speech and lipreading abilities are poor, a factor which has been attributed to asphasia.

Social Behavior

Miss D has limited opportunities to engage in activities with young people of her age due to the lack of organized clubs for young, single deaf men and women. Miss D enjoys numerous sports and has participated in them with both deaf and hearing people.

Initial Observations of Speech and Voice

The research teacher found it impossible to understand Miss D's attempts at speech. Consonants were usually omitted, rhythm was lacking, her voice quality was strained and gutteral, and her pitch fluctuated uncontrollably. Miss D's lipreading ability was poor. She experienced difficulty lipreading the simplest words.

Observations of Behavior During Sessions

Miss D applied herself seriously to the performance of each task. It was the impression of the research teacher that Miss D participated in the project not out of personal motivation but to accommodate the family's expectations. She communicated with the research teacher almost exclusively through fingerspelling. Miss D never initiated a conversation with nor offered an opinion to the research teacher. She merely responded obediently to questions asked of her and to the tasks which were presented.

Observations of Changes in Vocal Behavior

Miss D learned to produce a good falling inflection with both immediate and delayed feedback from IPPI. She learned to produce the intonation pattern for some phrases with immediate feedback from IPPI. Her speech rhythm improved a great deal.

Subject I-E, Male, age 20

Home Environment and Occupation

Mr. E lives with his hearing parents. He is employed as a radio packer.

History of Deafness

Mr. E was born deaf. The etiology of his deafness is unknown.

Visual Perception

Mr. E had a total time score of 8' 45" on the Witkin Imbedded Figures Test. His group rank was 2.

Education

Mr. E attended a school for the deaf for six years.

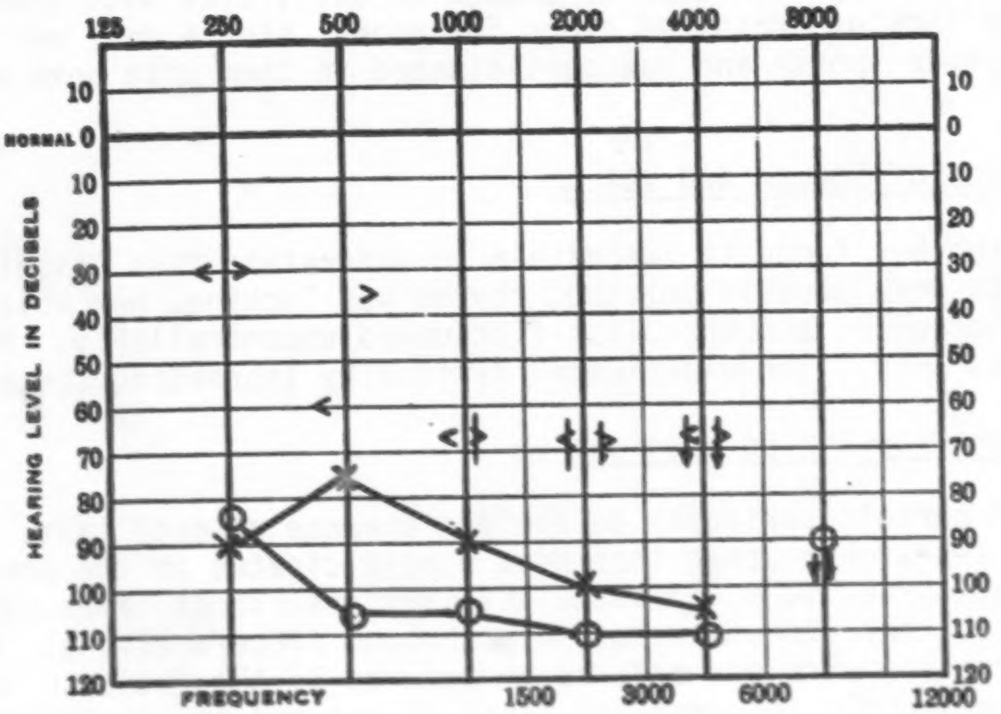


Fig. A-5. Audiogram for subject I-E.

Communicative Behavior

Mr. E uses the combined method of speech and sign language in order to communicate. He tries to make himself understood through speech alone. However, he generally fails and finds it necessary to supplement his speech with signs. His difficulties with speech and lipreading have been attributed to emotional problems.

Social Behavior

Mr. E makes overtures of friendship to everyone he meets. It does not appear to disturb him that both deaf and hearing people have difficulty in comphrehending his speech, and that he, in turn, does not understand them. He participates in numerous sports with both deaf and hearing people.

Initial Observations of Speech and Voice

Mr. E's speech was characterized by numerous articulation distortions and omissions. His lipreading ability was also poor. His voice quality was strained and nasal. Attempts at speech sounded like unconnected, nasalized grunts.

Observations of Behavior During Sessions

Mr. E's communication with the research teacher was accomplished primarily through signs and fingerspelling. Mr. E exerted a great deal of effort in his performance of each task, and he became disgusted with himself when after several attempts he did not achieve success. In his struggle to make a correct response, his entire body became rigid and in particular his oral mechanism. His efforts to produce inflectional changes were demonstrated primarily through intensity changes. In spite of his failures, Mr. E appeared to enjoy his participation in the program. He liked conversing with the research teacher who often had to terminate the discussion in order to proceed with the speech program.

Observations of Changes in Vocal Behavior

Mr. E learned to reproduce in conversation the correct rhythmic patterns for many of the expressions he had practiced. He also learned to produce accurate intonation patterns while sustaining the sound "ah".

Subject I-F, Female, age 37

Home Environment and Occupation

Mrs. F lives with her deaf husband and three hearing children in an upper middle class suburb. She has no occupation other than that of housewife at the present time.

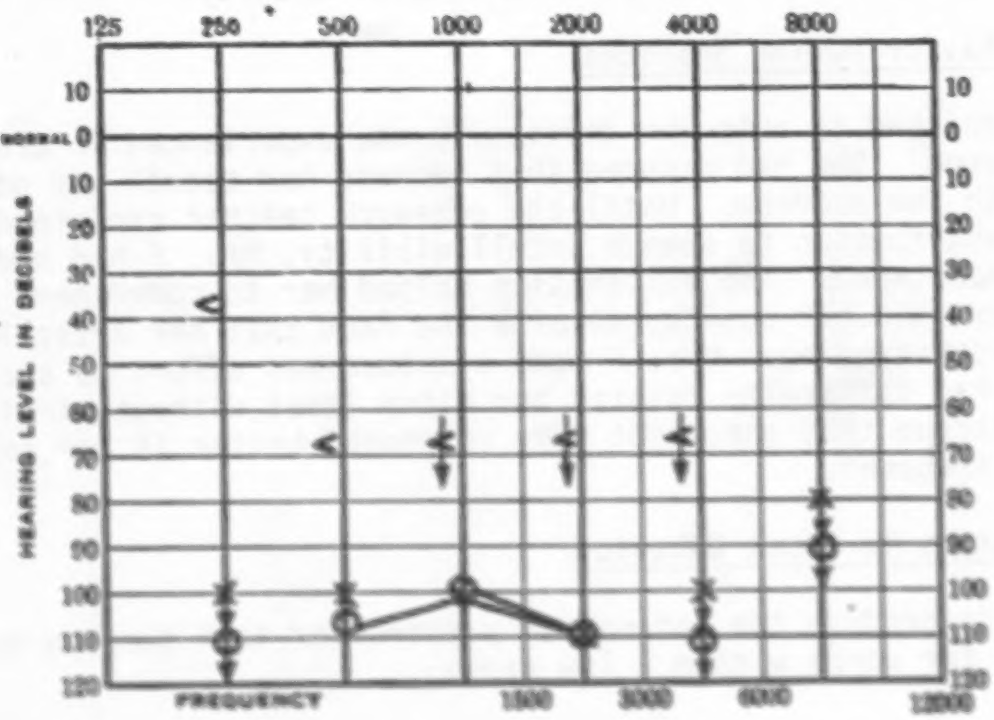


Fig. A-6. Audiogram for subject I-F.

History of Deafness

Mrs. F acquired deafness in infancy as a result of spinal meningitis.

Visual Perception

Mrs. F scored the lowest total time score on the Witkin Embedded Figures Test. Her total time score was 8' 40". Her group rank was 1.

Education

Mrs. F attended an elementary school for the deaf and a high school for the hearing.

Communicative Behavior

Mrs. F has always used the oral approach in communication. She has no knowledge of sign language.

Social Behavior

Mrs. F does not enjoy associating with most deaf people. She considers their interests mundane, and their communicative skills very limited. Mrs. F feels embarrassed when she sees deaf people communicating manually in the presence of hearing people. Mrs. F struggles constantly to improve herself by reading and studying vocabulary. She socializes frequently with hearing people.

Initial Observations of Speech and Voice

Mrs. F's speech and lipreading abilities were excellent. Her habitual pitch level was very low and her speech lacked inflectional changes. Her speech rhythm, however, was very good and gave her speech a natural quality.

Observations of Behavior During Sessions

Mrs. F was astonished to note the difficulty she experienced in producing the various pitch patterns. She had assumed that because her speech was good, she would have no trouble with the program. Until the research teacher explained the concept of pitch and its contribution to speech intelligibility, Mrs. F had had no prior knowledge of its importance. The explanation helped her to comprehend why people did not always understand her speech, despite the fact that her articulation and speech rhythm were outstanding. Mrs. F made a determined effort to succeed in each task; however, she had difficulty raising her pitch level without straining her voice. Mrs. F indicated that she might have responded better if her exposure to IPPI had been more frequent.

Observations of Changes in Vocal Behavior

Mrs. F learned to produce the intonation pattern for task phrases as well as the falling inflections for words within a low range.

Subject I-G, Male

Home Environment and Occupation

Mr. G lives with his deaf wife and three hearing children in a middle class suburb. He is employed as an accountant.

History of Deafness

Mr. G was born deaf as a result of the RH factor. He has three siblings, one of whom has a hearing impairment.

Visual Perception

Mr. G had a total time score of 25' on the Witkin Imbedded Figures Test. His group rank was 6.

Education

Mr. G attended a regular elementary school for three years and then a school for the deaf. Subsequently he attended a hearing high school and completed two years of college.

Communicative Skills

Mr. G has always used speech and lipreading in order to communicate. He has a knowledge of dactylology.

Social Behavior

Mr. G is very active in various organizations. He participates with hearing people in activities associated with his job and his children's school. However, he prefers socializing with deaf people and is involved in numerous clubs and organizations for the deaf.

Initial Observances of Speech and Voice

Mr. G's vocal quality was excessively nasal. His habitual pitch level was higher than average. Although he used inflections, they were not always appropriate, e.g. a rising inflection instead of a falling inflection. Mr. G's articulation and rhythm patterns were excellent and accounted for his highly intelligible speech.

Observations of Behavior During Sessions

Mr. G disliked the initial phases of the program. He complained of fatigue and throat strain while practicing the sustained pitch levels, and indicated that he would discontinue his participation in the program unless new tasks were introduced. He responded enthusiastically to the tasks which involved words and phrases and performed them in a relaxed and natural manner. Mr. G was fascinated by the relationship of pitch changes to a speaker's attitude and enjoyed informing his hearing friends about this phenomenon.

Observations of Changes in Vocal Behavior

Mr. G responded well to all of the pitch patterns presented and learned to use them in conversation when he concentrated upon doing so. Without much difficulty, he was able to apply the correct pattern to most new material.

Subject I-H, Female, age 63

Home Environment and Occupation

Miss H shares a house with two other deaf women. Previously, Miss H was employed as a photographer and subsequently as a researcher for an art museum. Due to illness and discrimination against the deaf, respectively, these jobs terminated and she is currently employed as a typist. She does not like her present job.

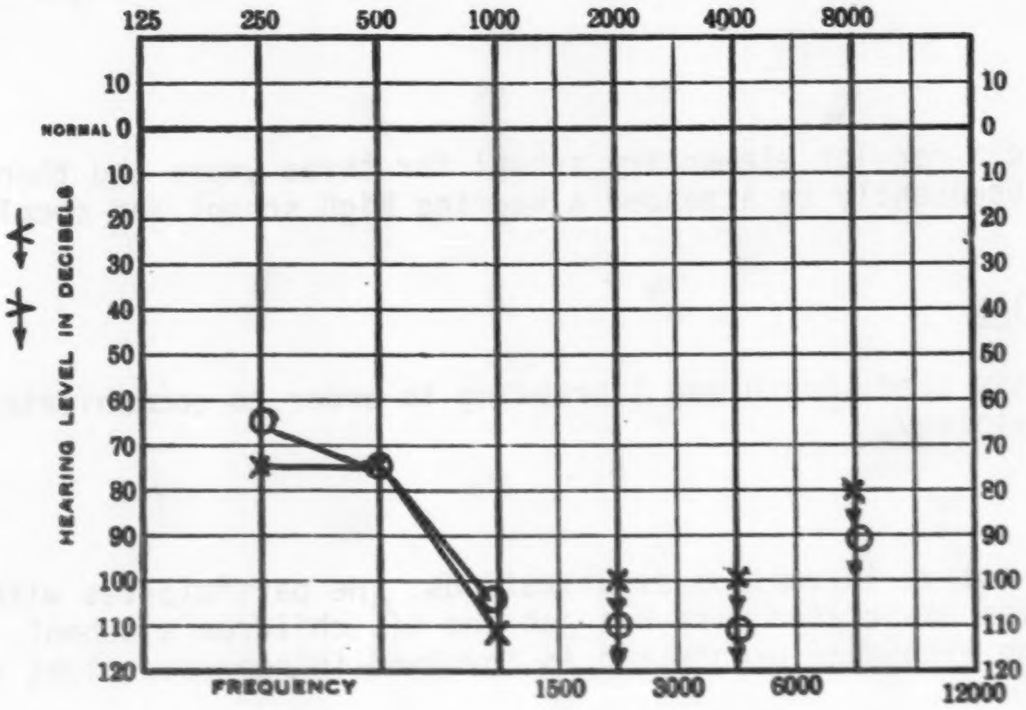


Fig. A-7. Audiogram for subject I-H.

History of Deafness

Miss H acquired her hearing loss at age 3 as a result of scarlet fever.

Visual Perception

Miss H had a total time score of 32' 30" on the Witkin Imbedded Figures Test. Her group rank was 7.

Education

Miss H attended an elementary school for the deaf and a high school for the hearing.

Communicative Behavior

Miss H has always used speech and lipreading in order to communicate. She has a knowledge of dactylology which she learned in order to be more socially accepted among the deaf population.

Social Behavior

Miss H expressed little desire for association with hearing people. She is angered by the treatment she received from her hearing employers at the art museum and resents the fact that hearing people at her present place of employment have not made overtures of friendship to her. Miss H is an avid reader and participates in most activities alone or with a few deaf friends.

Initial Observations of Speech and Voice

Miss H had an extremely hoarse voice which she attributed to a chronic post-nasal drip condition. Her speech, rhythm patterns and inflections were good. A slight Southern accent could be detected. (She was born and lived for a number of years in Virginia.) Her lip-reading ability was good; however she often nodded her head to acknowledge statements from the research teacher which she actually did not understand.

Observations of Behavior During Sessions

Miss H appeared to enjoy the opportunity to vary her life a bit by participating in the program. It was the impression of the research teacher that Miss H was not particularly concerned with improving her speech. She seemed to accept with resignation the fact that a response was incorrect and exerted little effort to improve upon it. Due to the hoarse quality of her voice, it was impossible for her pitch pattern to match the model pattern. Miss H related well to the research teacher and often voiced her complaints about the deaf person's hardships in a hearing world.

Observations of Changes in Vocal Behavior

The more conscious Miss H was of using appropriate inflections, the more strained and unnatural her speech sounded. She was able to produce a rising inflection with greater facility than any other pitch pattern.

Subject I-I, Female, age 44

Home Environment and Occupation

Mrs. I lives with her deaf husband and three hearing children in a middle class suburb. She has had numerous other jobs prior to her present occupation as a cafeteria cashier.

History of Deafness

The age of onset and etiology of Mrs. I's deafness are unknown. It occurred prior to the acquisition of speech.

Visual Perception

Mrs. I's total time score on the Witkin Embedded Figures Test was 35' 8". Her group rank was 8.

Education

Mrs. I attended a regular elementary school followed by attendance at a school for the deaf. Subsequently, she received a diploma from a regular high school and attended a preparatory school.

Communicative Behavior

Mrs. I has always used speech and lipreading to communicate. She has a limited knowledge of dactylology.

3

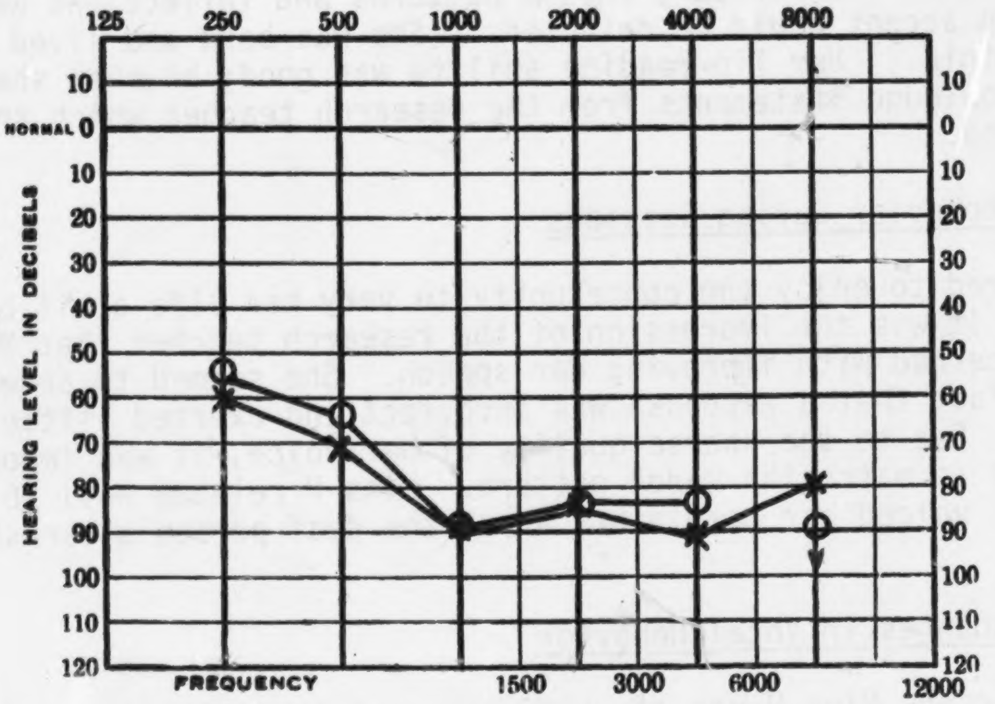


Fig. A-8. Audiogram for subject I-I.

Social Behavior

Mrs. I has been discouraged in her association with hearing people in group situations. Her complaint is that they lack the consideration to inform her of the progression of topics under discussion. She has terminated her participation in church affairs for this reason. Mrs. I is a warm, sensitive and jolly person. She enjoys family activities and is involved in numerous associations for the deaf.

Initial Observations of Speech and Voice

In the opinion of the research teacher, Mrs. I's speech was the most intelligible and most natural of all the deaf adults. Her habitual pitch level was low. Her use of falling inflections and intonation patterns was good within the low range.

Observations of Behavior During Sessions

Mrs. I derived a great deal of enjoyment from her participation in the program. She tried hard to respond satisfactorily to the tasks and was both surprised and amused by the errors she made. Mrs. I had difficulty raising her pitch level, and attempts at such generally resulted in a strained, unnatural voice. She was able to respond in her falsetto range, which was characterized by an uncontrollable vibrato, but was unable to make a good transition between her low habitual level and falsetto.

Observations of Changes in Vocal Behavior

Mrs. I learned to produce a natural rising inflection within her low pitch range.

APPENDIX B

Tabulations of Stimulus-matching Attempts and Successes by Subject I-C

In the following, NT refers to number of trials and NS to number of successful matchings:

A. Responses during Phase I.

TABLE B-I. Response for Sustained Low Pitch Pattern

	Stimulus Pattern Width in Semi-tones							
	3		2		1		0	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS
1	5	5	5	5	4	4	4	4
2	10	4	11	8				
3	3	2	15	6	15	6		
4	2	2	2	2	15	6		
5	5	3	5	3	4	4		
6	2	2	2	2	5	3	10	4
7	5	2	5	2	5	3	10	4
8	2	2	2	2	2	2	2	2
9	5	4	4	4	4	4	10	7
10	4	4	5	3	10	7	5	4

TABLE B-II. Response for Low Pitch to Medium Pitch Pattern

	Stimulus Pattern Width in Semi-tones							
	3		2		1		0	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS
1	25	8						
2	4	4	4	3	12	1		
3	20	10	5	1				
4	4	3	4	3	15	4		
5	25	12						
6	10	5	5	3	10	2		
7	5	3	20	4				
8	25	9						
9	15	6	10	6				
10	10	6	10	5	5	1		

TABLE B-III. Response for Low Pitch to High Pitch Pattern

	Stimulus Pattern Width in Semi-tones							
	3		2		1		0	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS
1	25	9						
2	4	3	8	3	8	1		
3	5	4	10	7	8	0		
4	3	2	5	3	15	3		
5	15	8	10	3				
6	5	3	20	6				
7	5	2	5	3	10	4	5	1
8	5	4	13	7				
9	5	4	10	5	10	0		
10	5	4	5	4	10	0		

TABLE B-IV. Response for Sustained High Pitch Pattern

	Stimulus Pattern Width in Semi-tones							
	3		2		1		0	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS
1	10	4	5	4	8	0		
2	5	2	5	3	12	1		
3	4	3	10	5	8	0		
4	4	2	4	3	13	2		
5	4	4	10	5	10	1		
6	5	2	9	3	10	0		
7	4	3	5	3	10	4	5	1
8	4	4	20	6				
9	5	4	20	8				
10	10	4	15	0				

TABLE B-V. Response for High to Medium Pitch Pattern

	Stimulus Pattern Width in Semi-tones							
	3		2		1		0	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS
1	25	5						
2	4	3	16	5				
3	10	5	14	6				
4	15	8	10	4				
5	15	4	10	2				
6	19	7	5	2				
7	5	3	15	5	5	0		
8	5	4	5	4	15	2		
9	25	8						
10	20	3						

TABLE B-VI. Response for Medium Pitch to Low Pitch Pattern

	Stimulus Pattern Width in Semi-tones							
	3		2		1		0	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS
1								
2	5	2	8	3	8	2		
3	9	6	8	6	5	3		
4	10	4	4	3	10	2		
5	25	8						
6								
7	15	3	5	2	5	0		
8	10	3	10	3	5	0		
9	15	5	5	0				
10	20	4						

B. Responses during Phase II

TABLE B-VII. Response for Low to Medium to Low Pitch Pattern

	Stimulus Pattern Width in Semi-Tones							
	3		2		1		0	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS
1	20	7						
2	15	9	5	1				
3	15	2	10	1				
4	25	6						
5	10	4	5	3	10	1		
6	25	10						

TABLE B-VIII. Response for Medium to High to Medium Pitch Pattern

	Stimulus Pattern Width in Semi-tones							
	3		2		1		0	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS
1	15	6	10	5				
2	5	3	20	6				
3	5	2	15	0				
4	15	5	10	2				
5	10	5	5	3	10	0		
6								

C. Responses during Phase III

TABLE B-IX: Response for Rising-decreasing Pitch Pattern (phrases) ⌒

Session No.	Phrase No. 1		2		3		4		5		6		7		8		9		10	
	NT	NS	NT	NS	NT	NS	NT	NS	NT	NS	NT	NS	NT	NS	NT	NS	NT	NS	NT	NS
1	10	5	6	4	3	3	25	5	3	3	6	5	5	4	3	3	100	10	3	3
2	3	1	3	1	3	0	3	0	3	2	3	2	3	3	3	1	3	2	3	3
2	3	0	3	2	3	2	3	3	3	3	3	2	3	3	3	1	6	1	3	3
4	3	3	20	10	3	3	6	3	3	3	5	2	3	3	3	3	6	3	3	3
5	12	2	3	3	3	2	5	2	3	3	3	2	3	3	5	2	3	2	3	2
6	10	2	12	6	8	3	6	4	6	3	5	3	3	3	5	3	6	4	3	3
7	8	5	10	7	10	2	10	1	3	3	4	3	3	3	4	3	6	3	3	3

Phrases:

1. How are you?
2. Good morning.
3. What's your name?
4. What day is it?
5. Where are you?
6. I like you.
7. Move over.
8. Get out of here.
9. Go quickly.
10. I mean it.

D. Responses during Phase IV

TABLE B-X. Response for Decreasing Pitch Pattern (words) ↘

	Expression									
	"Go"		"Now"		"Good"		"Oh"		"George"	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS	NT	NS
1	3	3	3	2	3	2	3	3	3	1
2	5	3	10	3	20	0	15	1	3	3
3	4	2	3	3	10	0	6	4	6	3
4	3	2	3	3	10	0	3	3	3	3
5	3	3	3	3	10	0	4	3	8	2
6	3	2	6	3	10	3	3	3	3	3

TABLE B-XI. Response for Increasing Pitch Pattern (words) ✓

	Expression									
	"Now"		"Fire"		"Go"		"George"		"Good"	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS	NT	NS
1	3	0	3	1	3	1	3	2	3	3
2	5	3	4	2	5	2	8	2	10	5
3	6	2	3	3	4	3	3	3	3	3
4	5	2	4	2	6	2	4	3	3	3
5	4	3	5	3	5	3	4	3	5	4
6	5	2	3	3	3	3	3	3	3	2

E. Response during Phase V (Delayed Feedback)

TABLE B-XII. Response for Increasing-decreasing Pitch Pattern (phrases, delayed feedback) ∧

Session No.	Phrase No. 1 NT	1 NS	2 NT	2 NS	3 NT	3 NS	4 NT	4 NS	5 NT	5 NS	6 NT	6 NS	7 NT	7 NS	8 NT	8 NS	9 NT	9 NS	10 NT	10 NS
1	3	2	3	3	3	0	3	1	3	1	3	1	3	1	3	0	3	2	3	1
2	3	3	3	3	3	1	3	2	3	2	3	2	3	2	3	1	3	2	3	2
3	3	2	3	3	3	2	3	3	3	3	3	0	3	2	3	1	3	2	3	0
4	3	2	3	3	3	1	3	2	3	3	3	1	3	2	3	2	3	1	3	2

Phrases:

1. I thought so.
2. He kicked me.
3. What time is it?
4. That's my book.
5. Who called me?
6. Good evening.
7. Talk softly.
8. Don't do that.
9. Dress nicely.
10. It's your turn

TABLE B-XIII. Response for Decreasing Pitch Pattern (words, delayed feedback) \

	Expression									
	"Fool"		"Well"		"Red"		"Hurry"		"No"	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS	NT	NS
1	3	2	3	0	3	0	3	0	3	3
2	3	0	3	0	3	0	3	0	3	0
3	3	2	3	0	3	0	3	0	3	3

TABLE B-XIV. Response for Increasing Pitch Pattern (words, delayed feedback) ✓

	Expression									
	"Fool"		"Well"		"Red"		"Hurry"		"No"	
Session No.	NT	NS	NT	NS	NT	NS	NT	NS	NT	NS
1	3	0	3	0	3	0	3	0	3	0
2	3	0	3	1	3	3	3	0	3	3
3	3	0	3	0	3	3	3	0	3	2

APPENDIX C

Listener's Answer Sheet for Adult Study

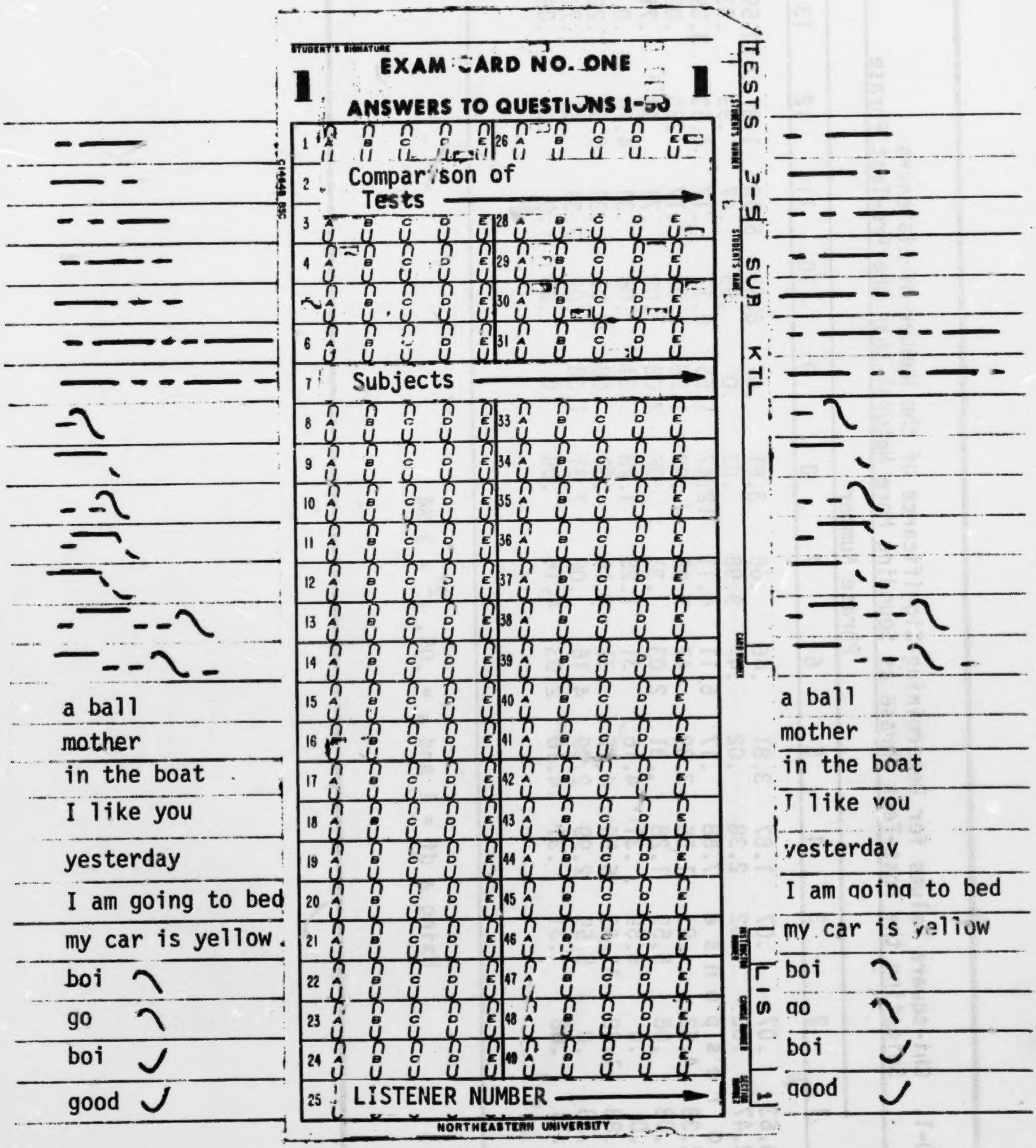

STUDENT'S SIGNATURE
EXAM CARD NO. ONE
ANSWERS TO QUESTIONS 1-50
Comparison of Tests
Subjects
LISTENER NUMBER
NORTHEASTERN UNIVERSITY
TESTS 3-S SUB KTL
LIS
a ball
mother
in the boat
I like you
yesterday
I am going to bed
my car is yellow
boi
go
boi
good

Fig. C-1 Phrases and patterns used in pre- and post-tests for adult subjects and data card for listener's judgements

APPENDIX D

Chi-square Data - Adult Study

TABLE D-1. Chi-square Values for Determining Significance of the Number of Listeners Selecting the Post-Test Phrase as Sounding More Natural than the Pre-Test Phrase

Subject	Phrase Number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
A	6.63	.07	.07	1.87	3.81	.66	.66	3.81	.07	6.63	5.10	1.87	10.59
B	12.47	.02	.02	2.38	.02	.47	9.98	.02	.0	.93	.47	.93	.93
C	No response			7.88	.17	6.11	6.11	12.47	1.56	6.11	.17	4.63	3.39
D	2.38	4.63	.93	1.56	3.39	.47	7.88	.93	1.56	.02	.17	.93	.02
E	.08	.08	5.59	1.28	.31	2.03	.31	.08	2.03	.08	.71	.08	.71
F	.0	.0	5.59	.31	4.16	.31	1.28	1.28	.31	.08	.31	4.16	.0
G	11.83	1.28	11.83	5.59	4.16	.31	4.16	.31	.08	2.03	.31	5.59	1.28
H	1.28	.0	5.59	2.99	2.99	4.16	.08	7.31	1.28	.08	7.31	.31	.71
I	.71	.08	.31	.31	4.16	2.03	4.16	.08	.0	.08	.0	.08	.08

Using a df = 1 and $\alpha = .05$, $x^2 = 3.84$

APPENDIX E

A Pilot Project with Five Deaf Children

Five deaf children participated in a pilot project which was conducted after completion of the program for deaf adults. As one aspect of the process of revising the adult program, for use with children, five deaf children were involved in a pilot program with Phase I of the adult program (see Sev. V-C-2). The following is a report of each subject's responses to the training:

Subject P-A, Female, age 7, 3 hours of machine time.

Initial Impressions of Speech and Voice

Subject P-A's vocal intensity was weak and her pitch range was high. Her speech was generally unintelligible to the research teacher.

Observations of Behavior During Sessions and Changes in Vocal Behavior

Initially, Subject P-A was unable to phonate with sufficient intensity to produce a clear pattern on the oscilloscope. With the aid of an intensity meter, she subsequently increased her vocal intensity. In response to Phase I of the adult program, Subject P-A succeeded only in sustaining "ah" at the pitch level H. She was unable to lower her pitch or to produce any kind of pitch shift from one level to another.

During one session in which she engaged in spontaneous babbling, Subject P-A responded in a lower and more natural pitch range. In addition there were occurrences of pitch changes, however, these changes were spontaneous and not voluntarily produced.

Subject P-B, Male, age 7, 3 hours of machine time.

Initial Impressions of Speech and Voice

Subject P-B's vocal quality was relatively natural. His habitual pitch level was within normal limits and occasional inflections were detected during speech. It was the impression of the research teacher that subject P-B was able to receive some pitch information through hearing. His speech was characterized by numerous sound omissions, particularly at the endings of words.

Observations of Behavior During Sessions and Changes in Vocal Behavior

Subject P-B succeeded in sustaining "ah" at both L (low) and H (high) pitch levels. He was able to shift from one level to another, e.g. L-H, however, he was unable to make the pitch transition between the two levels. He found it easier to produce a rising pitch shift than a falling one.

Subject P-C, Male, age 12, 3 hours of machine time

Initial Impression of Speech and Voice

Subject P-C's voice quality was hoarse and strained, and his speech was generally unintelligible to the research teacher.

Observations of Behavior During Sessions and Changes in Vocal Behavior

Subject P-C experienced difficulty in phonating with sufficient intensity. With the aid of an intensity meter, however, he eventually increased his intensity. He was able to sustain "ah" at pitch level H, but for most of the teaching period he was unable to phonate at any other level. During the final sessions he learned to make gross and slight pitch changes to and from pitch levels H and M. However, he was unable to produce the pitch transition between the two levels.

Subject P-D, Female, age 12, 3 hours of machine time.

Initial Impressions of Speech and Voice

Subject P-D's habitual pitch level was within normal limits. Inflections were practically absent from his speech. His articulation ability was good except for occasional sound omissions.

Observations of Behavior During Sessions and Changes in Vocal Behavior

Subject P-D was able to sustain "ah" at the various pitch levels indicated to her. In addition, she was able to produce the pitch shifts and transitions; her responses, however, were inconsistent. It was the impression of the research teacher that this subject received some pitch information through hearing.

Subject P-E, Male, age 12, 3 hours of machine time

Initial Impressions of Speech and Voice

Subject P-E's habitual pitch range was high. His speech was characterized by numerous sound omissions and distortions and by choppy rhythm patterns.

Observations of Behavior During Sessions and Changes in Vocal Behavior

Subject P-E was unable to produce any of the pitch tasks involved in Phase I. He was able to sustain "ah" for 2 secs. but not at a predesignated pitch level. During production of the stressed syllable "bah" and the unstressed syllable "bu" in various rhythm patterns, he succeeded in producing a rising pitch change each time he produced the stressed syllable "bah".

APPENDIX F

Description of Communicative Behavior and Audiograms for Deaf Children

Subject II-A (Ann), age 10

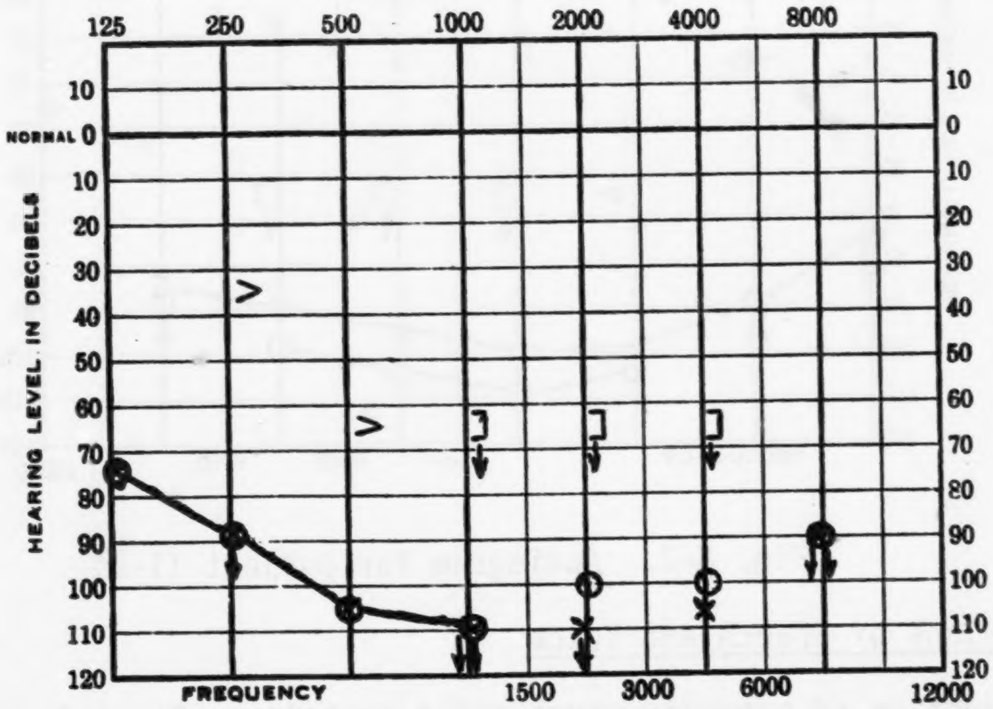


Fig. F-1. Audiogram for subject II-A.

Initial Observations of Speech and Voice

Ann had no control over her pitch which fluctuated erratically between a normal range and falsetto. Generally, however, it was very high and of weak intensity. Articulation was characterized by numerous omissions, particularly the final endings of words. Lipreading ability was fair.

Observation of Behavior During Sessions

Ann's attitude was usually influenced by her classmate, Marie. Contingent upon Marie's behavior during each session, Ann's response to the research teacher was either cooperative or antagonistic. Ann enjoyed competing with Marie in the performance of the various tasks and was motivated by this competition to do well.

Observation of Changes in Vocal Behavior

Ann learned most of the rhythm, pitch and falling inflection patterns; until the last few sessions, however, she was able to produce these patterns only within her falsetto range. Then, during the spontaneous period of one session she uttered the word "pink" within a normal pitch range. Consequently she used "pink" as a pitch reference for other words. After repeated practice, she was able to produce the single word falling inflection tasks within a normal pitch range.

Subject II-B (Bonnie). age 9

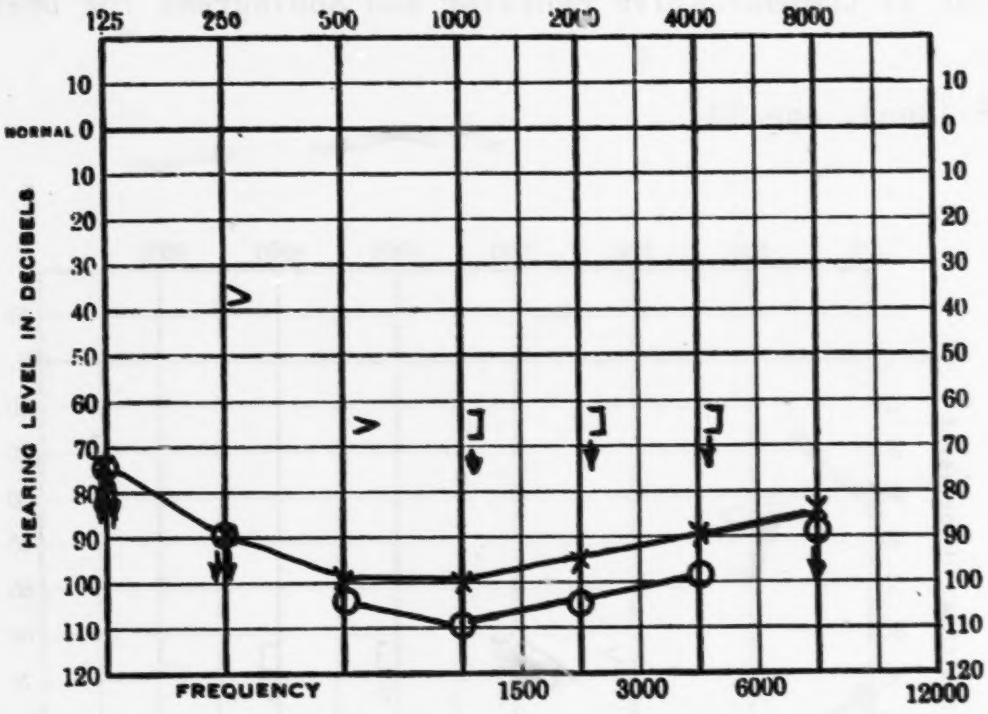


Fig. F-2. Audiogram for subject II-B.

Initial Impressions of Speech and Voice

In her production of everyday words and expressions, Bonnie's vocal quality was relatively natural. In contrast, her production of less frequently-used speech was characterized by a strained vocal quality and a higher habitual pitch level. Her use of inflections was minimal. Speech rhythm was good, as was lipreading ability. Articulation was characterized by frequent omissions of word endings. Speech intelligibility, however, was good.

Observations of Behavior during Sessions

Bonnie was a happy, effervescent child. She was a diligent pupil who seemed highly motivated to do well in any task that was undertaken. It took a number of sessions before she was able to produce a significant pitch change. During this period, she grew neither discouraged nor impatient. Bonnie gradually learned to produce all the required pitch changes. Accompanying the pitch changes, however, were dramatic intensity changes: low pitch was soft while high pitch was loud.

Observations of Changes in Vocal Behavior

Bonnie learned to perform the rhythm tasks in a relaxed, natural manner. She learned to produce the various pitch tasks, most of which were uttered within the normal pitch range. Vocal quality was imparied, however, by excessive variations in intensity.

Subject II-C (Carl), age 13

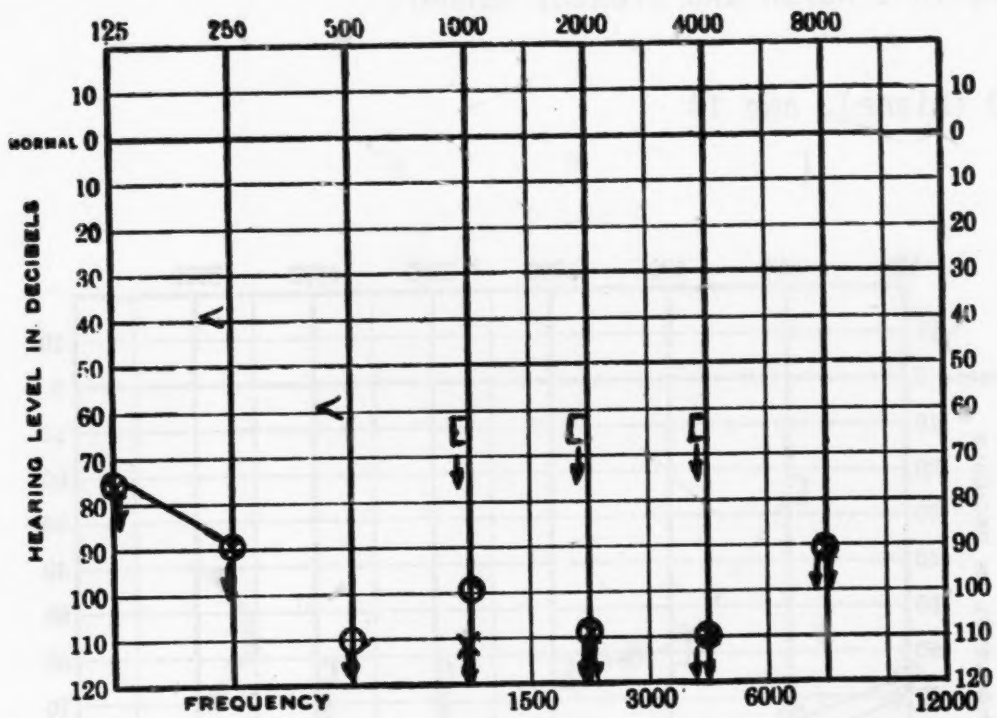


Fig. F-3. Audiogram for subject II-C.

Initial Observations of Speech and Voice

Carl's voice quality was somewhat strained, but the overall vocal effect was considerably more natural than that of the majority of children who participated in the speech program. His habitual pitch level was within normal limits, and he made occasional use of falling inflections. Carl's speech rhythm was choppy because he did not generally make vocal transitions from one syllable to another, and the syllables were uttered rapidly. Articulation was characterized by numerous omissions. Lipreading ability depended to a great extent on whether or not Carl wanted to understand what was being spoken.

Observations of Behavior During Sessions

During the first few speech sessions, Carl was timid and extremely co-operative. Once he became familiar with the research teacher and the speech program, his conduct altered dramatically. He began to initiate all sorts of pranks which would draw attention to himself, both from his classmate and the research teacher. In particular, he attempted to prove his strength by inflicting various physical abuses on his own body. Often he reconstructed fights he had engaged in with other children. He seemed to derive great pleasure from hurting himself.

Carl became less co-operative during sessions with IPPI and was often hyperactive. He enjoyed producing various visual patterns, but wasn't always amenable to practicing the pattern indicated by the research teacher. He applied himself earnestly to those tasks which he desired to undertake.

Observations of Changes in Vocal Behavior

Carl learned to produce the rhythm and pitch tasks, and the falling inflection for single words and short phrases. He achieved a rising inflection; it was uttered, however, in a harsh and breathy manner.

Subject II-D (Diane), age 14

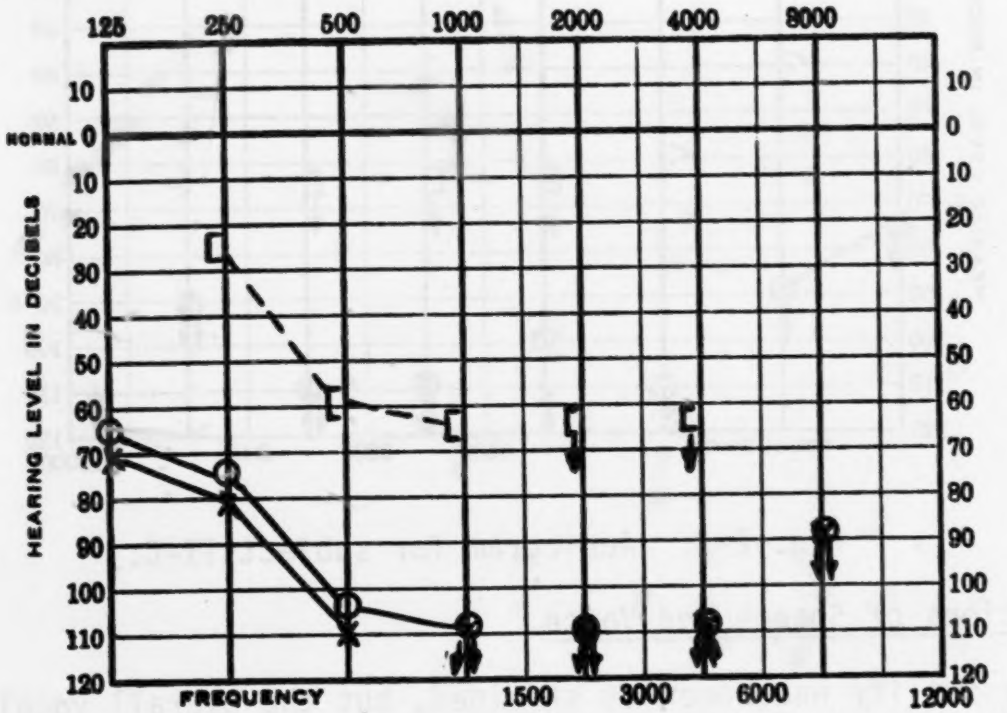


Fig. F-4. Audiogram for subject II-D.

Initial Impressions of Speech and Voice

Diane's vocal quality was hard and strained. Her pitch fluctuated within a wide range; pitch changes, however, were not under control. Diane's speech rhythm was good; a slight southern Negro accent could be detected. Articulation was characterized by numerous omissions and lipreading ability was fair.

Observations of Behavior During Sessions

Diane was very friendly and cooperative. She was easily excitable and reacted to each visual pattern with amazement. Diane tried very hard to produce each pattern. Before performing, she gave careful consideration to the task and then indicated that she anticipated success. Consequently, she was astounded and incredulous if her production was dramatically incorrect (e.g. substitution of falling for rising inflection). She would attribute the error to machine malfunction and require proof from the research teacher that it was not. Diane liked talking to the research teacher and often described in detail (with the aid of drawings) her meaningful experiences.

Observations of Changes in Vocal Behavior

Diane developed much better control over her pitch and learned to confine it, for the most part, within normal limits. Consequently, her vocal quality became more relaxed and natural. She learned to produce the patterns for most task items. The rising inflection task provided the most difficulty; after Diane learned it, however, she responded consistently well.

Subject II-E (Eddie), age 15

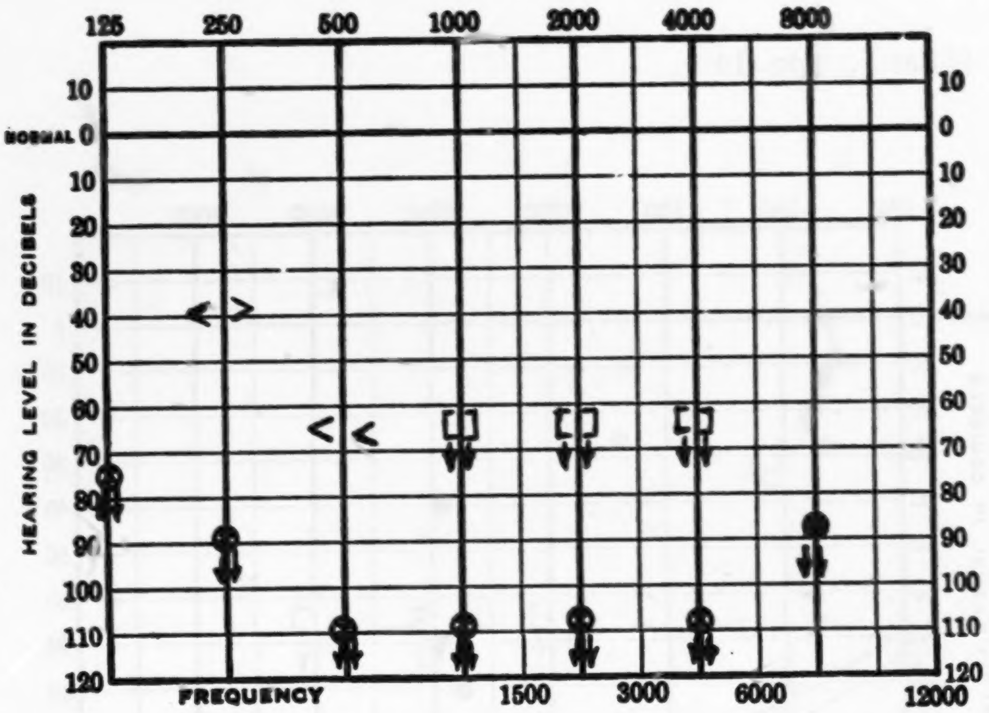


Fig. F-5. Audiogram for subject II-E.

Initial Impressions of Speech and Voice

Eddie's vocal quality was hoarse and was characterized by little, if any, pitch changes. Speech was uttered very slowly and laboriously. Articulation was characterized by countless omissions and distortions, rendering speech unintelligible most of the time. Lipreading ability was poor.

Observations of Behavior During Sessions

Despite the fact that Eddie's communication abilities were poor, he was generally understood by the research teacher through use of gestures and objects or pictures.

Eddie was a very lethargic child who may have had a motor disability which affected articulatory functions. Frequently, his lips and tongue seemed unable to function in the coordinate manner required to produce natural rhythm and speech.

Eddie was extremely cooperative for the duration of speech instruction, despite the fact that he achieved minimal success with the program. In the rhythm tasks he experienced trouble with the duration of syllables and had a tendency to recite stressed syllables with voice and unstressed syllables with breath. After much practice during sessions and at home, Eddie was able to produce the rhythm patterns correctly. However, without continuous reinforcement, his performance deteriorated drastically. During the final session, for the first time, Eddie produced a pitch change - a falling inflection.

Observations of Changes in Vocal Behavior

Eddie succeeded in performing the tasks at a more rapid rate. He learned to perform the rhythm tasks, though his responses were inconsistent.

Subject II-F (Fran), age 14

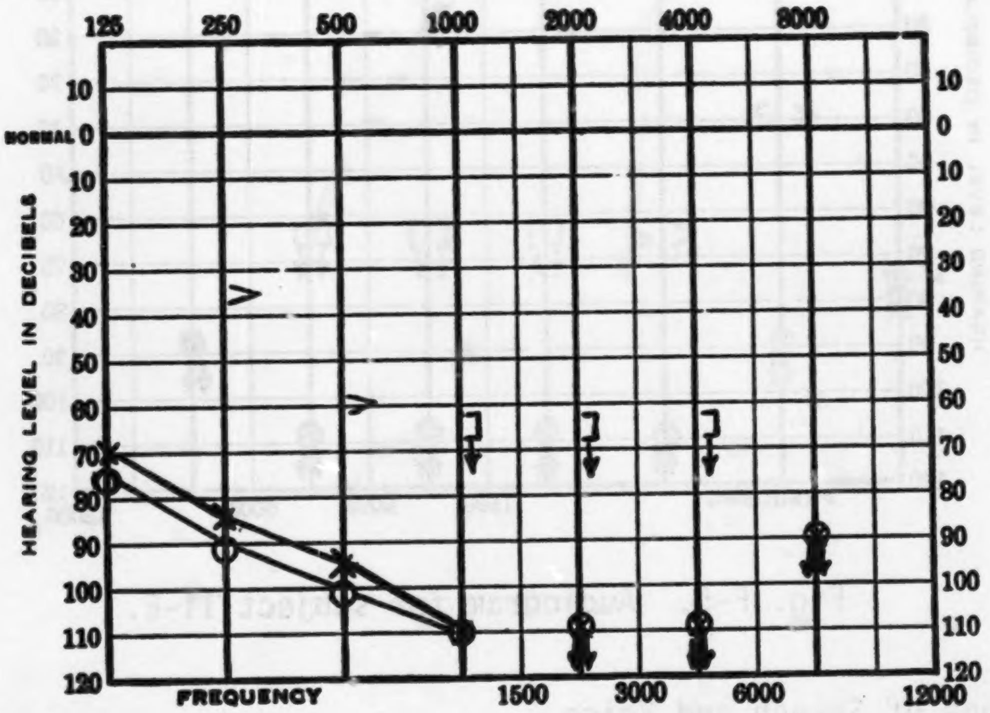


Fig. F-6. Audiogram for subject II-F.

Initial Impressions of Speech and Voice

Fran's vocalizations started off with sufficient intensity but grew weak towards the end of the utterance. Her habitual pitch level was within normal limits; pitch changes, though occasionally present, were uncontrolled. Articulation was characterized by a tendency to clip off the final endings of words. Lipreading was poor. Speech rhythm was mechanical.

Observations of Behavior During Sessions

Fran had a delightful personality and she made every session very pleasant. She learned the rhythm tasks quickly and well. The pitch changes, in contrast, were very difficult for her. After much practice, she was able to produce two sustained levels: her habitual level and falsetto. She learned to shift from one level to the other.

She could not, however, make the transitions between the levels which were essential for good rising and falling inflection. Despite repeated failure, Fran continued to respond to the program with interest and enjoyment.

Observations of Changes in Vocal Behavior

Fran learned to perform the rhythm tasks satisfactorily and with good vocal intensity. Words and phrases, though not produced with inflection, were uttered with more natural speech rhtyhm.

Subject II-G (Gail), age 11

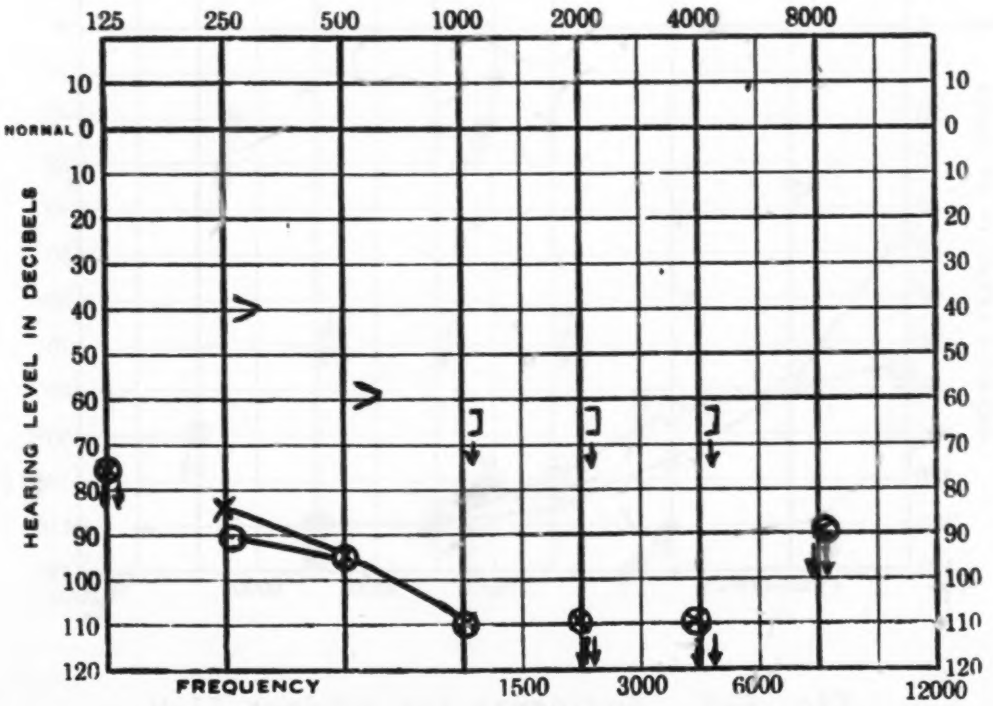


Fig. F-7. Audiogram for subject II-G.

Initial Observations of Speech and Voice

Gail's voice fluctuated between a strained, gutteral low pitch level and falsetto. Natural inflections were absent from her speech. Words were uttered in a labored arhythmic manner, syllable by syllable. Articulation and lipreading abilities, affected by Gail's bilingual environment, were poor.

Observations of Behavior During Sessions

Gail's speech was generally unintelligible to the research teacher. She was rarely frustrated in her desire to communicate, however. Either she drew pictures or had her classmate explain. Gail approached the speech program with enthusiasm and determination. She made continual progress for the duration of the program. Each success motivated her to exert more of an effort on those task items which were difficult. She derived great pleasure from demonstrating her accomplishments to her classmate.

Observations of Changes in Vocal Behavior

Gail learned to maintain her pitch within normal limits and to produce most task items in a relaxed and natural manner. She experienced greatest difficulty with the rising inflections. During the final session, however, she managed to make an approximate, if not exact, production of the rising inflection pattern.

Subject II-H (Harry), age 13

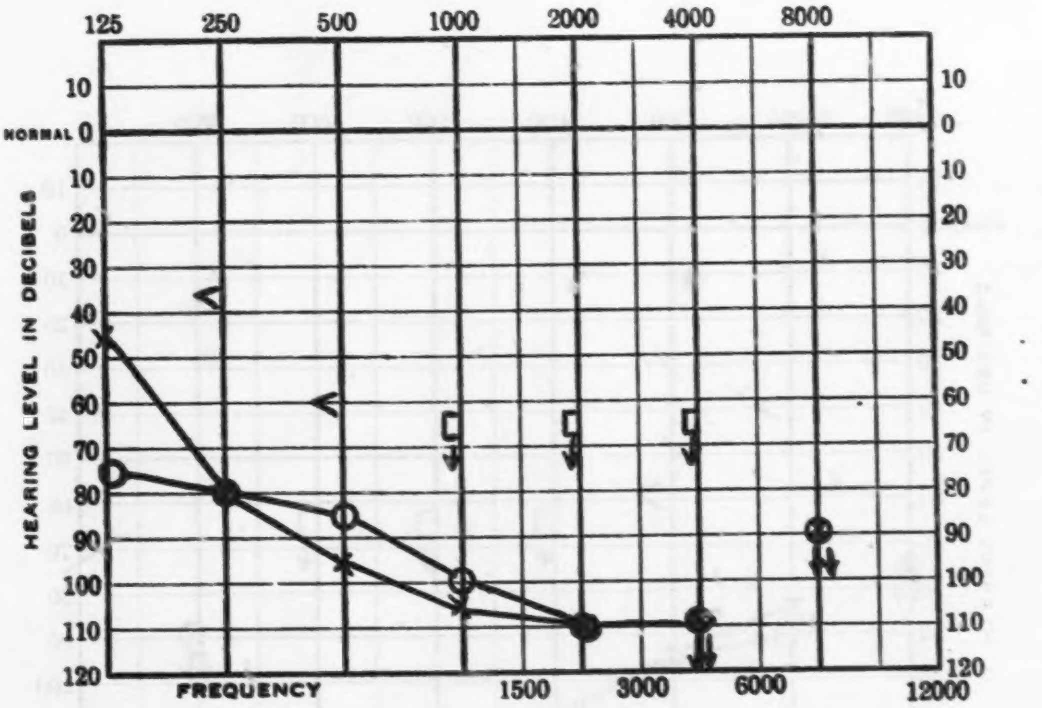


Fig. F-8. Audiogram for subject II-H.

Initial Impressions of Speech and Voice

Harry's vocal quality was generally strained and loud and somewhat high in pitch. His use of falling inflections for single-word expressions was good. Other pitch changes were apparent in his speech, though they were usually inappropriate. Harry's lipreading ability was fair. His articulation was characterized by occasional distortions and omissions.

Observations of Behavior During Sessions

Harry was highly distractable during speech sessions. He was easily antagonized by his classmate, Norman, and responded in kind to Norman's pranks with complete disregard for the research teacher's reprimands. Harry was fascinated by the visual pattern displays, and during some sessions seemed quite intent on producing exact matches of the model patterns. Harry was also intrigued with the manipulation of the various dials on the oscilloscope, and sometimes spent entire sessions experimenting with the dials and attempting to create new visual patterns. He was obviously more concerned with the mechanics of the IPPI than with improving his speech.

Observations of Changes in Vocal Behavior

As Harry became more familiar with the test words and phrases, his habitual pitch level became lower and his vocal quality became more natural. Harry learned to produce the rhythm tasks; he had difficulty, however, in uttering the syllables rapidly enough. He learned to perform all the pitch tasks; he was inclined, however, to alter his intensity when changing pitch.

Subject II-I (Ira), age 11

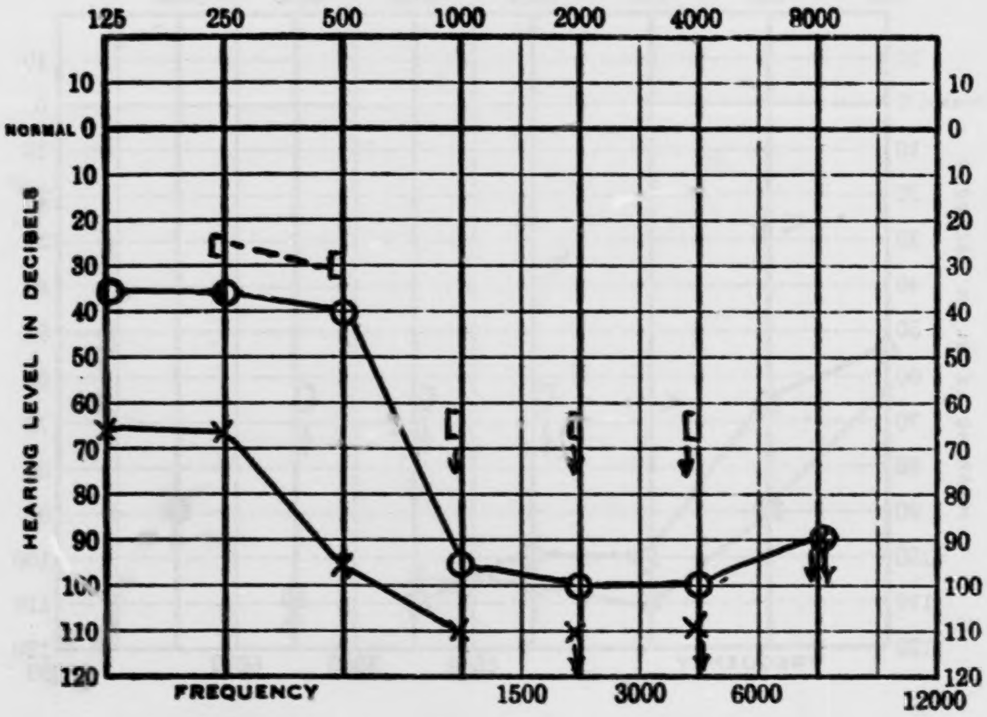


Fig. F-9. Audiogram for subject II-I.

Initial Impressions of Speech and Voice

Ira's habitual pitch level was within the normal range and his use of inflections was good. His lipreading ability was very good, though he appeared to receive supplementary aid from his hearing. His speech rhythm was natural and his articulation ability was good in comparison with the other children; it was believed, however, that Ira's articulation distortions were far too many in consideration of his other speech and hearing abilities

Observations of Behavior During Sessions

During the first speed session Ira was able to produce correct patterns for most task items, including the rising inflection task. In subsequent sessions he improved his performance by "listening" to the productions of the research teacher. In order to assure herself that Ira was actually hearing, the research-teacher removed the written card, covered her mouth to prevent him from lipreading, and produced various task items at random. Ira responded appropriately every time. After Ira could produce all the task items, the research teacher decided to stress the articulation of these words and phrases. Prior to this time, Ira had found it easy to succeed and had been very cooperative. The articulation phase of instruction, on the other hand, was difficult and frustrating for him, and he readily admitted defeat in preference to practice.

Observations of Changes in Vocal Behavior

Ira succeeded in producing all task items with the proper inflection.

Subject II-J (Joan), age 11

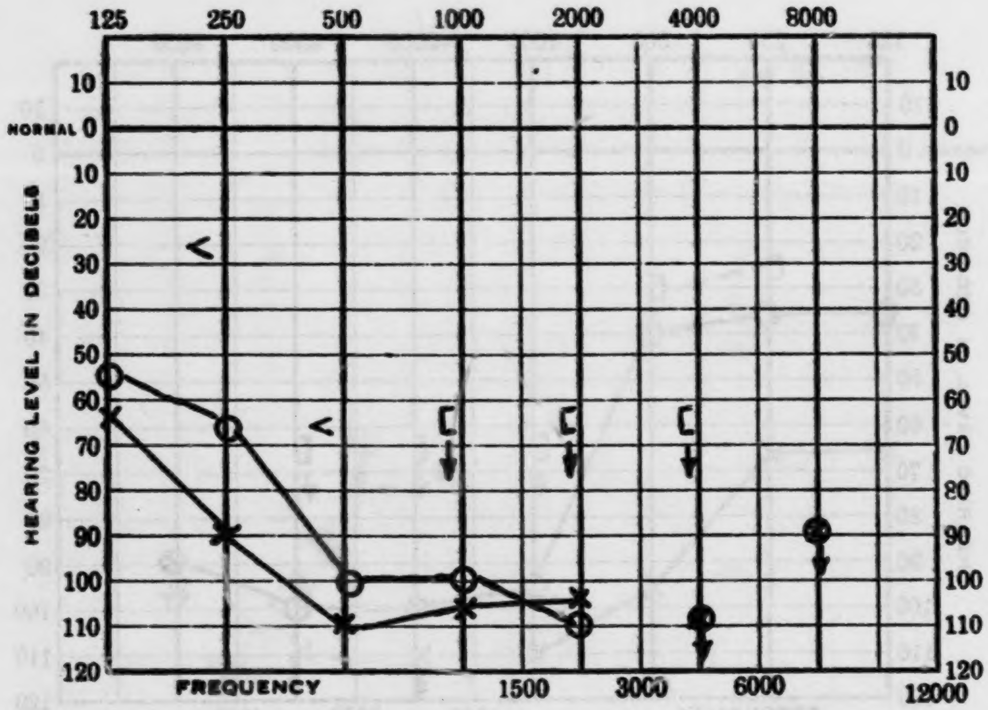


Fig. F-10. Audiogram for subject II-J.

Initial Observations of Speech and Voice

Joan's articulation and lipreading abilities were good; speech rhythm was choppy. Her habitual pitch level was within normal limits and inflections were used, though often inappropriately. Her voice quality was breathy.

Observations of Behavior During Sessions

Joan seemed eager to participate in the speech program for the first six weeks of instruction. She worked diligently at producing the task patterns and made dramatic improvements. Joan was a hyperactive child who was excitable and moody. While she achieved success she was happy, cooperative and highly motivated. When she failed a task after repeated efforts, she became angry and vindictive. At these times she would overturn chairs, tear up papers or scream at the teacher, and refuse to continue her lesson. After six weeks of instruction, Joan reached a learning plateau and experienced no further successes while experiencing the same repeated failures (e.g. the rising inflection tasks). Her behavior became very disorderly and it was decided to discontinue her participation in the program.

Observations of Changes in Vocal Behavior

Joan learned to produce the rhythm tasks, the pitch tasks and some intonation patterns (words and phrases taking a falling inflection). Her vocal quality and speech rhythm also improved.

Subject II-K (Kathleen), age 15

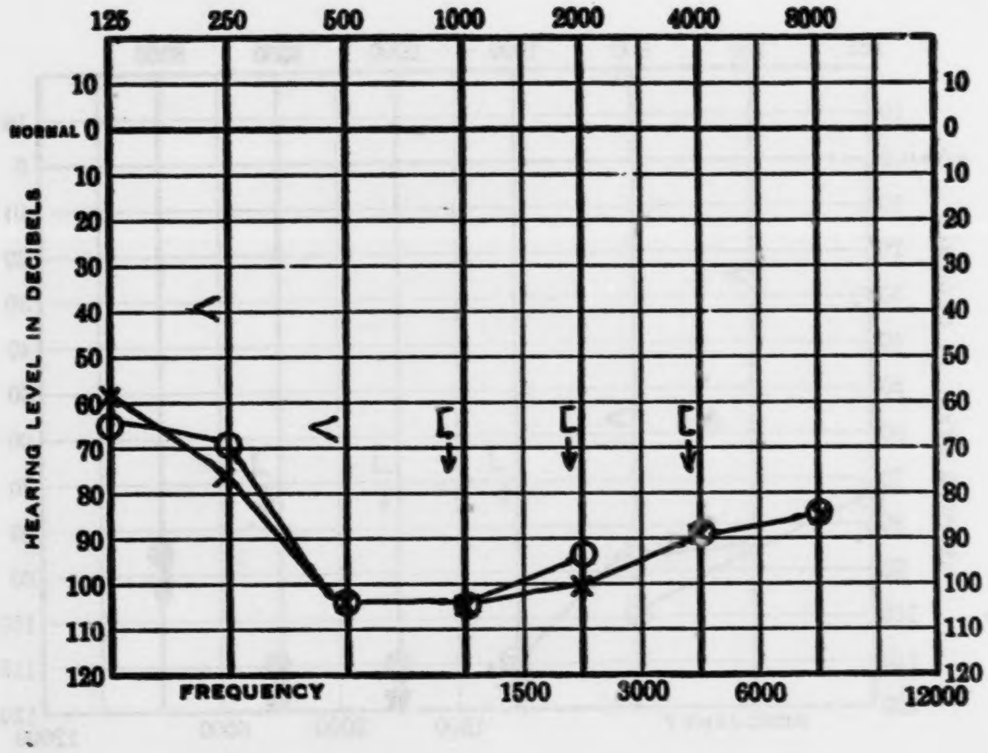


Fig. F-11. Audiogram for subject II-K.

Initial Impressions of Speech and Voice

Kathleen's vocal quality was strident and excessively nasal. Her speech was practically devoid of inflections. Altogether these characteristics rendered a very unpleasant vocal effect. Kathleen's speech rhythm was good. Articulation was characterized by a tendency to clip off the final endings of words. Lipreading ability was fair.

Observations of Behavior During Sessions

Kathleen was not at all motivated to do well in the program. Two factors appeared responsible for this attitude: Kathleen was the oldest girl involved in the speech program, and the object of derision from her classmates who considered speech instruction an activity for the younger children. In addition, Kathleen already seemed resigned to the belief that her speech could not improve. Consequently, she performed as instructed to do, but made no effort to produce the task items satisfactorily. Her poor performance of most of the task items served only to reinforce her negative attitude.

Observation of Changes in Vocal Behavior

Kathleen learned to perform the rhythm tasks well. She did not succeed, for most of the time, in producing any pitch change except for an involuntary utterance, in conversational speech, of an approximate rising inflection. Finally, she learned to apply this inflection to some words comprising the rising inflection task.

Subject II-L (Larry), age 11

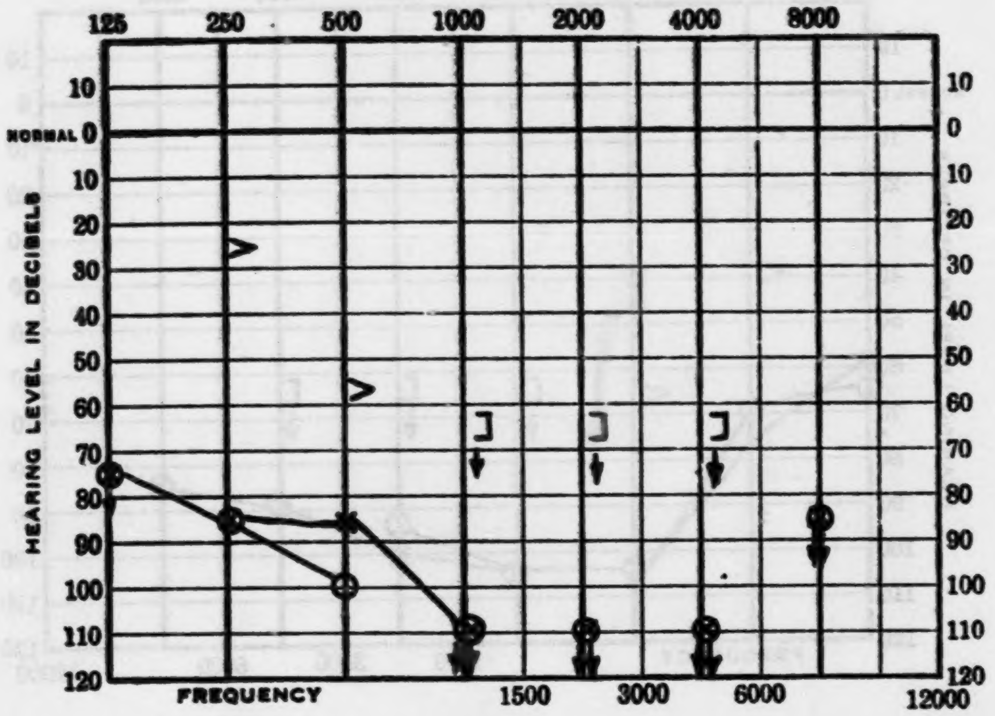


Fig. F-12. Audiogram for subject II-L.

Initial Impressions of Speech and Voice

Larry's vocal quality was breathy. His habitual pitch level was within normal limits and his use of inflections, when he concentrated on using them, was good. Larry's speech intelligibility was good, though he was inclined to omit sounds occasionally. Lipreading ability was very good.

Observations of Behavior During Sessions

Larry participated in the program for one month. Then, on account of a time-conflicting interest, he terminated instruction. During his participation in the program, Larry appeared to find the tasks challenging and made noticeable improvements. He could not have been more cooperative. It was with surprise, therefore, that the research teacher learned of Larry's decision to discontinue.

Observations of Changes in Vocal Behavior

Larry learned to perform most task items with the proper rhythm and inflection. However, he was unable to produce a rising inflection.

Subject II-M (Marie), age 9

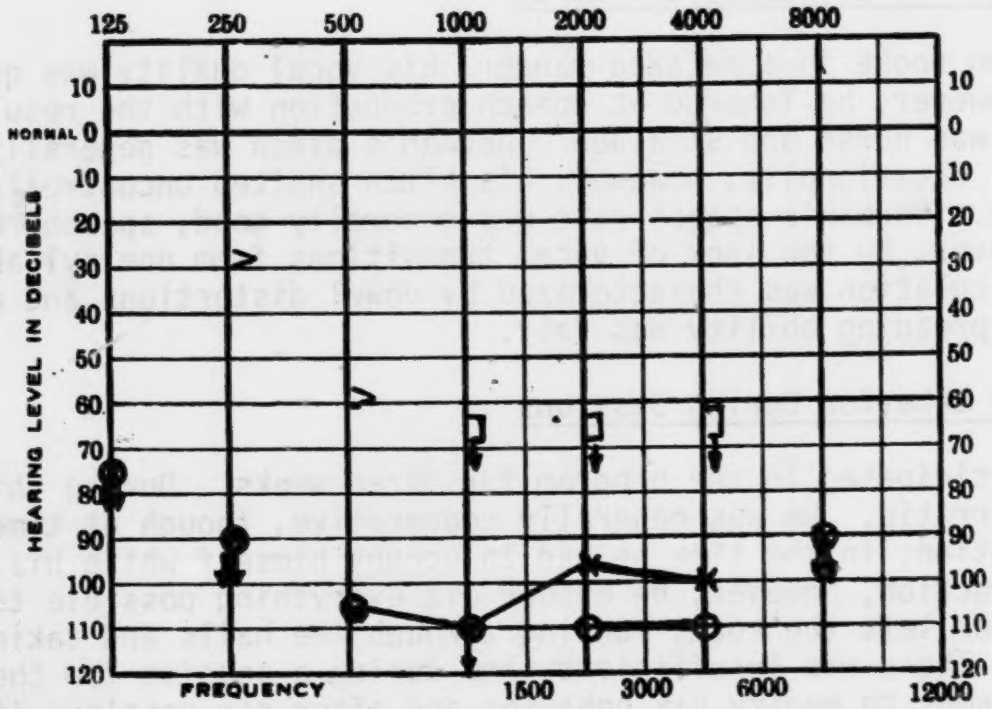


Fig. F-13. Audiogram for subject II-M.

Initial Impressions of Speech and Voice

Marie's pitch range was very high and her vocal intensity was weak. Marie did not exert much effort in speech production. Her articulation was sloppy and characterized by countless omissions. Lipreading ability was fair. Speech rhythm was poor.

Observation of Behavior During Sessions

Marie's behavior was erratic. Sometimes she was shy, soft spoken and submissive. At other times, she was aggressive (to the point of physically hurting her classmate), loud and self-willed. During the first two months of instruction she was generally cooperative and made a determined effort to perform the tasks well. The last few sessions, however, were completely unproductive. Marie was consistently antagonistic and uncooperative without apparent motive. Her school teacher confirmed this conduct in the classroom and attributed the cause to family problems.

Observations of Changes in Vocal Behavior

Marie learned to lower her pitch level for sustained vowel sounds. She was unable, however, to maintain the low level for speech. In addition, she improved her production of the rhythm, pitch and falling inflection patterns.

Subject II-N (Norman), age 12

Initial Impressions of Speech and Voice

When Norman spoke in a relaxed manner, his vocal quality was quite natural. More often, however, he labored at speech production with the result that his vocal quality was harsh and strained. Norman's pitch was generally within normal limits; occasionally, however, his pitch shifted uncontrollably into falsetto range. Norman's speech rate was generally good, speech rhythm was impaired, however, by the lack of vocal transitions from one syllable to another. Articulation was characterized by vowel distortions and consonant omissions. Lipreading ability was fair.

Observation of Behavior During Sessions

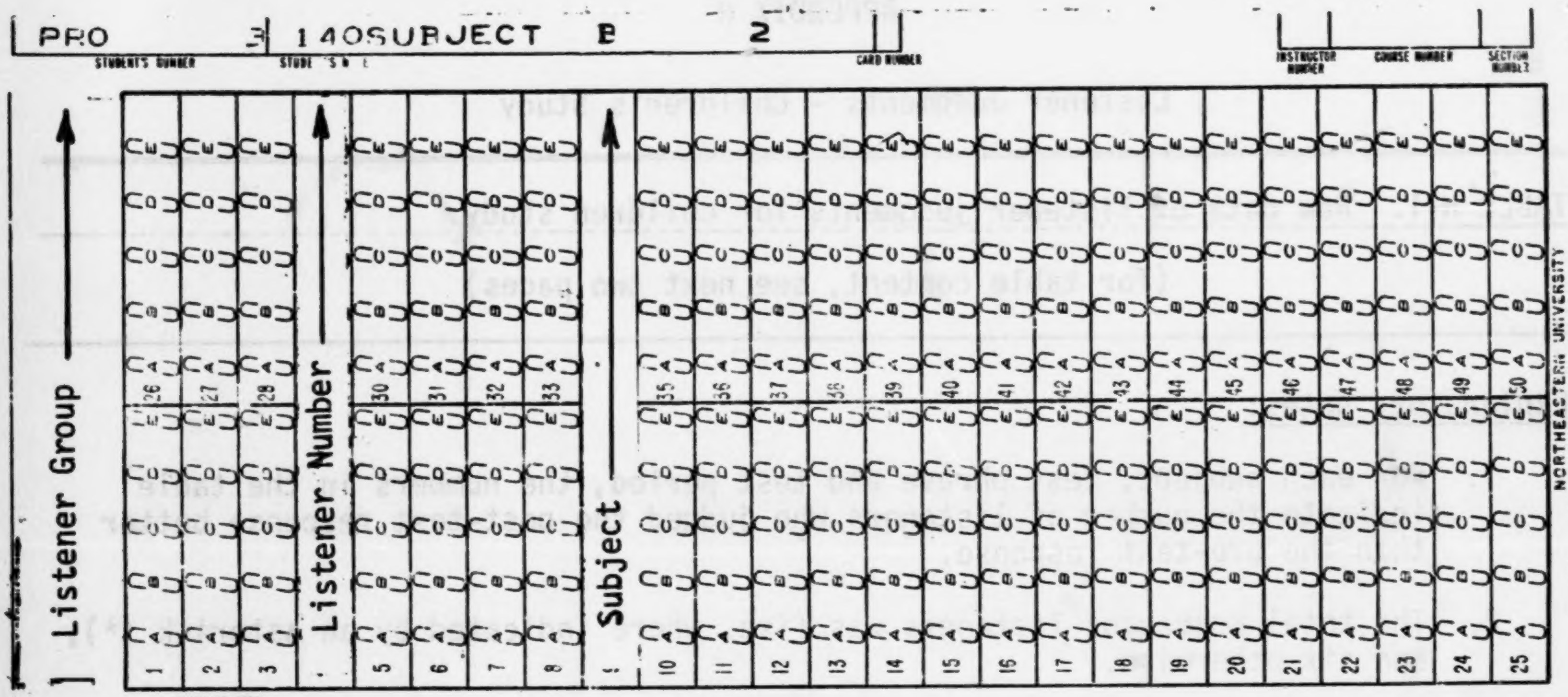
Norman participated in the program for three weeks. During this period, his behavior was erratic. He was generally cooperative, though at times grudgingly, during instruction; in the time he had to occupy himself while his classmate received instruction, however, he either did everything possible to distract his classmate or left the room, running through the halls and taking rides in the elevator. There was insufficient time during a session for the research teacher to attempt to modify his behavior and after six sessions it was decided to discontinue his participation in the program.

Observations of Changes in Vocal Behavior

In the short time Norman participated in the program, he learned to produce all the rhythm tasks, most of the pitch tasks involving stressed and unstressed syllables, and some of the tasks involving words and phrases. During attempts at producing single words with a falling inflection, he responded instead with a good rising inflection. Yet he was unable to produce a rising inflection at the appropriate times.

APPENDIX G

Listener's Answer Sheet for Children Study


PRO 3 140SUBJECT B 2
STUDENT'S NUMBER
CARD NUMBER
INSTRUCTOR NUMBER
COURSE NUMBER
SECTION NUMBER
Listener Group
Listener Number
Subject
A B C D E
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50
NORTHEASTERN UNIVERSITY
C14648 BSC

1. How are you? Fine, thank you.
2. Yesterday it rained.
3. The man went home.
4. The man you were talking to went home.
5. What time is it? Four thirty-five.
6. I always eat a lot.
7. Whenever I read I eat a lot.
8. Stop, look & listen.
9. Whose car did you use? My father's.
10. Honesty is the best policy.
11. Are you leaving now? Yes.
12. Bring me the kinves, the forks & the spoons.
13. What have you been doing all afternoon? Painting.

25. If you have had more than casual experience with speech of the deaf, fill in A.

Fig. G-1. Phrases used in pre- and post-tests for children-subjects, and data card for listener judgments.

APPENDIX H

Listener Judgments - Children's Study

TABLE H-1. Raw data of listener judgments for children study.

(for table content, see next two pages)

Explanatory notes:

1. For each subject, test phrase and test period, the numbers in the table indicate the number of listeners who judged the post-test response better than the pre-test response.

2. The total number of listeners was five, where indicated by an asterisk (*), and six otherwise.

3. Certain "0" responses in the table correspond to the cases when no judgment was made (as opposed to an actually performed judgment, in which none of the judges preferred the post-test response); such irrelevant zeros are crossed out in the table.

SUBJECTS	A	B	C	D	E	F	G	H	I	J	K	L	M	N
PHRASE 1														
TESTS 1-2	6	3	6	3	6	3	6	3	3	6	5	1	1	6
TESTS 2-3	1	3	2	5	2	5	0	5	6	3	1	~~0~~	1*	~~0~~
TESTS 3-5	4	1	4	3	0	2	3	3	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 2														
TESTS 1-2	5	1	3	5	6	5	3	3	3	6	2	1	0	6
TESTS 2-3	5	6	1	0	1	1	0	1	0	3	4	~~0~~	2*	~~0~~
TESTS 3-5	1	4	3	5	0	0	5	4	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 3														
TESTS 1-2	6	6	4	1	3	4	6	0	1	6	4	2	1	6
TESTS 2-3	1	3	3	5	6	5	0	5	6	2	3	~~0~~	3*	~~0~~
TESTS 3-5	5	2	2	5	2	1	4	5	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 4														
TESTS 1-2	6	3	2	2	6	3	6	5	4	6	4	1	3	4
TESTS 2-3	2	4	2	3	6	4	2	1	5	0	5	~~0~~	1*	~~0~~
TESTS 3-5	4	1	2	4	1	4	5	4	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 5														
TESTS 1-2	4	4	3	3	4	5	5	1	1	6	5	0	4	3
TESTS 2-3	3	6	1	3	5	4	0	4	3	2	5	~~0~~	0*	~~0~~
TESTS 3-5	0	2	3	6	1	5	4	3	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 6														
TESTS 1-2	6	5	6	5	3	6	6	5	~~0~~	5	5	4	5	4
TESTS 2-3	3	6	3	5	3	2	1	4	~~0~~	2	2	~~0~~	1*	~~0~~
TESTS 3-5	4	2	1	5	5	0	0	1	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 7														
TESTS 1-2	5	1	5	5	6	6	5	~~0~~	6	5	2	6	6	6
TESTS 2-3	0	6	4	4	1	1	1	6	4	6	3	~~0~~	1*	~~0~~
TESTS 3-5	5	3	3	5	6	3	3	4	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 8														
TESTS 1-2	5	2	4	2	6	6	1	3	4	6	1	0	4	4
TESTS 2-3	1	4	3	3	4	5	5	3	4	2	4	~~0~~	0*	~~0~~
TESTS 3-5	5	6	4	3	4	2	0	3	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 9														
TESTS 1-2	4	6	1	1	5	1	3	4	4	6	3	6	3	2
TESTS 2-3	6	2	0	1	3	5	3	3	4	5	5	~~0~~	0	~~0~~
TESTS 3-5	5	0	1	4	2	4	2	6	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 10														
TESTS 1-2	5	0	1	2	6	4	2	5	2	6	2	1	2	3
TESTS 2-3	1	6	2	0	2	3	3	3	4	4	1	~~0~~	1*	~~0~~
TESTS 3-5	6	4	1	2	3	1	2	1	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 11														
TESTS 1-2	4	5	6	~~0~~	5	6	3	3	2	6	5	1	6	5
TESTS 2-3	1	3	6	~~0~~	4	6	0	1	4	2	1	~~0~~	2*	~~0~~
TESTS 3-5	2	3	4	4	2	2	4	6	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 12														
TESTS 1-2	3	3	4	0	6	3	2	5	3	3	3	4	5	3
TESTS 2-3	0	2	3	4	4	3	5	3	3	4	4	~~0~~	1*	~~0~~
TESTS 3-5	5	5	2	4	1	0	2	4	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 13														
TESTS 1-2	5	6	5	0	5	6	4	5	6	5	6	6	6	6
TESTS 2-3	5	3	1	3	5	1	1	3	1	3	1	~~0~~	1*	~~0~~
TESTS 3-5	2	5	4	3	6	4	1	1	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~

SUBJECTS	A	B	C	D	E	F	G	H	I	J	K	L	M	N
PHRASE 14														
TESTS 1-2	6	5	5	3	6	4	3	3	6	6	5	6	2	5
TESTS 2-3	5	4	0	4	1	3	1	3	2	2	1	~~0~~	3*	~~0~~
TESTS 3-5	3	3	2	2	5	1	0	2	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 15														
TESTS 1-2	4	1	3	2	6	5	4	5	0	6	3	6	0	1
TESTS 2-3	2	5	6	3	4	2	2	3	4	1	6	~~0~~	3*	~~0~~
TESTS 3-5	4	3	2	2	1	1	3	6	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 16														
TESTS 1-2	4	5	5	1	4	1	0	4	5	~~0~~	5	1	1	6
TESTS 2-3	0	4	3	~~0~~	6	2	4	1	4	5	6	~~0~~	1*	~~0~~
TESTS 3-5	5	4	6	3	2	4	3	2	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 17														
TESTS 1-2	1	2	5	4	0	1	0	0	2	~~0~~	0	5	2	4
TESTS 2-3	6	4	4	1	4	2	6	5	3	3	4	~~0~~	4*	~~0~~
TESTS 3-5	5	2	1	3	2	2	6	3	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 18														
TESTS 1-2	3	5	3	4	0	1	1	5	1	4	4	1	0	2
TESTS 2-3	1	2	~~0~~	3	1	4	1	2	4	0	4	~~0~~	0*	~~0~~
TESTS 3-5	3	5	~~0~~	2	3	6	5	6	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 19														
TESTS 1-2	1	2	2	4	1	5	5	4	4	0	0	0	3	2
TESTS 2-3	5	3	5	5	5	0	3	1	1	4	4	~~0~~	2*	~~0~~
TESTS 3-5	2	6	4	1	0	4	1	4	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 20														
TESTS 1-2	2	1	1	4	4	3	1	1	6	5	2	0	1	1
TESTS 2-3	4	~~0~~	2	0	1	5	1	3	2	3	3	~~0~~	4*	~~0~~
TESTS 3-5	2	~~0~~	2	2	4	3	3	3	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 21														
TESTS 1-2	6	4	2	0	2	~~0~~	3	3	2	4	5	0	0	2
TESTS 2-3	4	1	0	5	5	2	2	5	4	6	6	~~0~~	5*	~~0~~
TESTS 3-5	1	3	6	3	3	4	3	6	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 22														
TESTS 1-2	6	2	0	1	5	4	3	4	5	2	6	4	6	~~0~~
TESTS 2-3	0	5	5	6	2	3	5	1	3	0	4	~~0~~	2*	~~0~~
TESTS 3-5	1	4	5	3	0	2	0	3	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 23														
TESTS 1-2	6	0	2	1	2	4	6	1	6	6	1	5	4	~~0~~
TESTS 2-3	5	4	3	2	5	1	3	5	2	3	2	~~0~~	2*	~~0~~
TESTS 3-5	2	2	3	5	4*	1	3	1	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 24														
TESTS 1-2	2	3	0	1	0	5	4	0	4	4	1	2	1	~~0~~
TESTS 2-3	1	4	6	6	5	3	5	0	6	3	3	~~0~~	4*	~~0~~
TESTS 3-5	6	3	6	4	3	5	4	5	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~
PHRASE 25														
TESTS 1-2	2	4	1	0	6	1	~~0~~	1	2	5	6	4	1	~~0~~
TESTS 2-3	4	~~0~~	5	4	4	4	4	3	1	~~0~~	1	~~0~~	5*	~~0~~
TESTS 3-5	2	~~0~~	4	6	4	3	6	4	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	~~0~~

APPENDIX I

Logarithmic Function Approximation.

As indicated in Sec. V-A-2-a, it is preferable to present the voice fundamental frequency on a logarithmic scale, i.e., it is desired to generate a logarithmic display of the frequency of the pitch-indicating pulses. This measurement is to be obtained from the calculation of the period between two consecutive pulses. The approximation used is

$$\log_2(cf) = 1.4427 \ln(cf)$$
$$\approx A(e^{au}-1) + B(e^{bu}-1) \quad . \tag{1}$$

A series expansion for the natural logarithm is

$$\ln(cf) \approx \sum_{n=1}^{\infty} u^n/n \tag{2}$$

where

$$u = 1 - 1/cf \quad . \tag{3}$$

On the other hand, when series expansions are used for the exponential functions, the logarithmic function of (1) can be approximated as

$$\log_2(cf) \approx \sum_{n=1}^{\infty} (u^n/n!)\,(Aa^n+Bb^n) \quad . \tag{4}$$

Both infinite series used converge at u = 0, or cf = 1. In view of this, the center of the frequency band over which the logarithmic approximation is desired is placed at f = 1/c. When the series are truncated at the fourth term, (2) becomes

$$\ln(cf) \approx u + (1/2)u^2 + (1/3)u^3 + (1/4)u^4 \quad , \tag{5}$$

and (4) gives

$$\log_2(cf) \approx (Aa+Bb)\,u + (1/2)\,(Aa^2+Bb^2)u^2$$
$$+ (1/6)\,(Aa^3+Bb^3)\,u^3 + (1/24)\,(Aa^4+Bb^4)u^4 \quad . \tag{6}$$

A comparison of equal powers of u yields a set of simultaneous equations for A, B, a, b. Solving for b results in the equation

$$b^5 - 7b^4 + 17b^3 - 19b^2 + 10b-2 = 0 \quad . \tag{7}$$

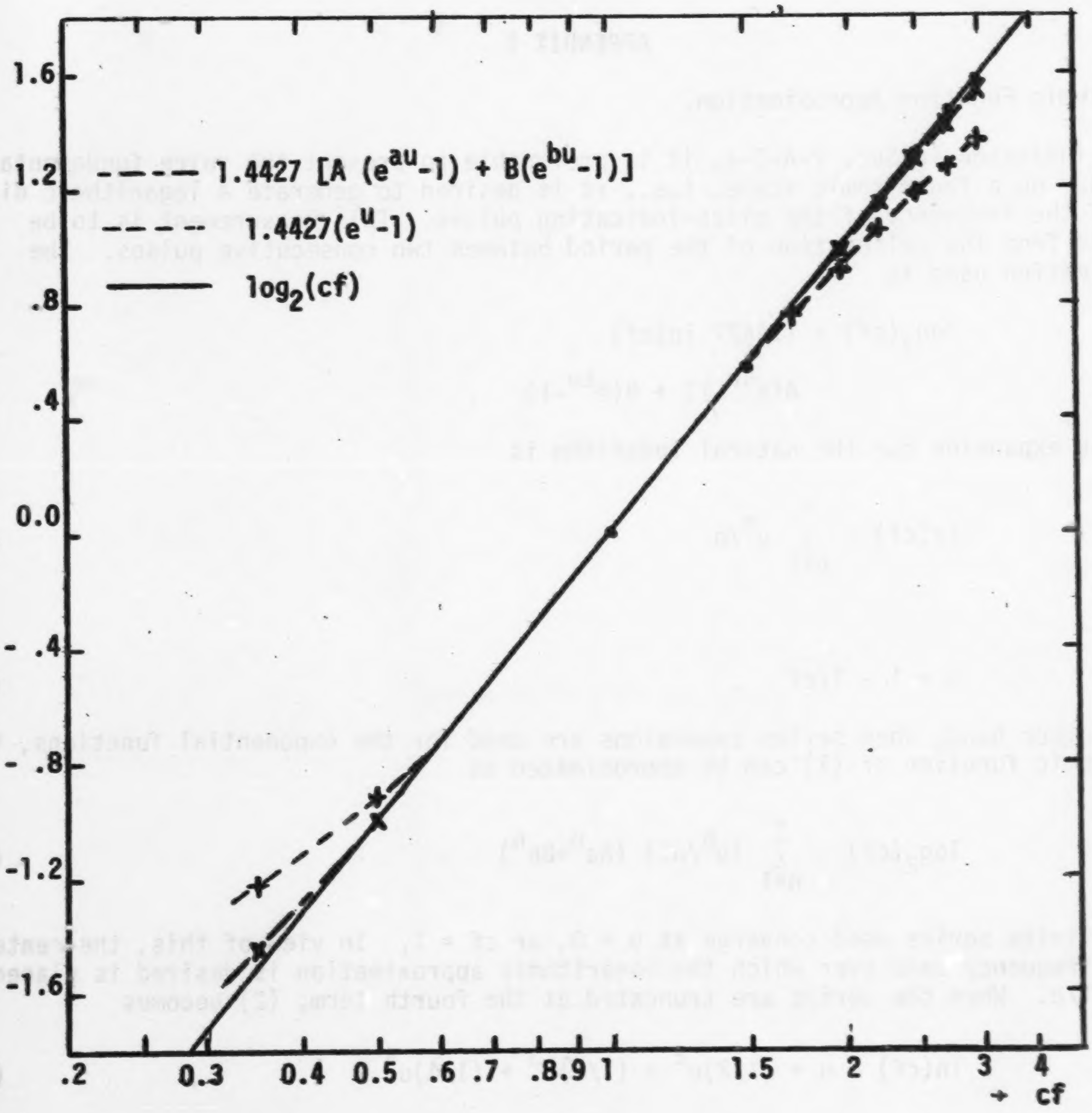


Fig. I-1. Approximations to log(cf); if represents normalized frequency.

A solution of this last equation on a computer gave the following three real roots:

$$b = 1,\ 0.5855,\ 3.4140\ . \qquad (8)$$

When these values of b are substituted into the set of simultaneous equations mentioned above, the value $b = 1$ gives an undefined value of B; however, the other two real roots can be used to obtain the remaining constants A, B, and a. For either of these two roots the final approximation obtained is

$$\log_2(cf) \approx 3.775\ \exp(-0.5858/cf) + 1.881\ \exp(-3.414/cf) - 2.1640\ . \qquad (9)$$

This approximation is shown in Fig. I-1, which, for comparison presents also an approximation using only one exponential term.* With the new approximation using two exponentials, the maximum error within the range $0.5 < cf < 2.5$ is 1%.

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* See Appendix B, ref. 9.

APPENDIX J

Use of IPPI with a Five Year Old Deaf Child

The research teacher of the deaf used the IPPI with a five-year old deaf child over a period of a year and a half. A total of 25 hours was spent with the unit. The following is a report of child's responses to the training provided.

Initial Impressions of Speech and Voice

Richard's vocal quality was natural and his vocalizations consisted of numerous involuntary inflections. He babbled constantly. Few real words, however, were detected in his vocalizations.

Observations of Behavior During Sessions and Changes in Vocal Behavior

For the first 6 months of speech sessions, Richard exhibited a short attention span and a great deal of hyperactivity. Yet, he appeared intrigued with the oscilloscope and derived much pleasure from producing various patterns himself. He did not regard the teacher's patterns as meaningful and seemed to consider her patterns as interruptions of his play with the novel visual device. The teacher, therefore, permitted Richard to vocalize spontaneously and interrupted him only to introduce stimulus objects and pictures to which he might respond with new vocal patterns, and to indicate her approval of the visual patterns he produced. Each session lasted for as long as Richard wanted to remain which was approximately 15 minutes.

After 6 months, Richard began to respond more favorably to the teacher's participation in his play with IPPI. He began to take notice of the teacher's patterns, e.g. the sound "ah" sustained for 2 seconds and the babbling of numerous repetitions of the sound "bu" and eventually attempted to produce them himself. Success came quickly to him.

Since then, Richard has continued to enjoy using IPPI and has been extremely cooperative in complying with directions from the teacher. Though sessions are more structured with the teacher introducing material at the beginning of each session, they remain informal so that Richard can switch to whatever material happens to interest him at the particular time. The duration of each session has lengthened to approximately 30 minutes, and Richard continues to designate the end of the session.

In addition to babbling and sustaining a sound for 2 seconds, Richard has learned to produce the stressed syllable "bah" and the unstressed syllable "bu" in various rhythm patterns. He is aware of the falling inflection pattern and points it out to the teacher whenever it occurs on the oscilloscope during his spontaneous speech. Recently he has learned to produce the falling inflection pattern while saying his name.

APPENDIX K

Calibration and Operation

In this section the assembly and calibration is described. It is assumed that the circuits described in the previous sections are built on removable printed circuit boards which are inserted in the order indicated. Prior to turning the unit on, the intensity should be set to its minimum value, the presentation selector set to NORMAL, and the board containing the circuits of Fig. 35 inserted, otherwise a fuse in the -100v supply will blow.

1. Vertical and Horizontal Deflection Amplifier.

Adjust both amplifiers (Fig. 35a) in the following manner: Load the input with a 5k resistance. Balance the outputs (collector of Q1 and Q2) with the potentiometer on the collector of Q4. Then obtain 160v at each output by adjusting the potentiometer on the emitter of Q4.

2. Pitch-Detector Input Gain.

Add the pitch detectors (Fig. 26) for each channel. Set the microphone gain (5k potentiometer on input A1(26)-2)so that a 12v output pulse is just produced with an input having the minimum vocal effort which is desired to produce a visual pitch pattern. The same procedure is used to set the gain for the Aux. input (5k potentiometer on the input A2(26)-2).

3. Trigger Sensitivity.

Add the trigger generators (Fig. 31a). Set the sensitivity (25k potentiometer on the base of Q1), so that a trigger is produced at LA(31) - 4 or LA(31) - 1 when the input is created with a minimum of vocal effort. This sensitivity should not be too great, otherwise noise will trigger the sweep.

4. Sweep Rate and Horizontal Alignment.

Add the sweep generator (Fig. 31b) and control (Fig. 32). Adjust the mode switch to CFFT, depress the PITCH switch, and apply an auxiliary input (Fig. 26) to activate the trigger generator. Adjust 50k potentiometer (Fig. 31b) for a desired sweep time (2 sec. recommended), as monitored at the sweep output. Increase the beam intensity so that the writing beam is just visible. Readjust the balance on the horizontal deflection amplifier (see under "1" above), so that the trace begins at the left-hand graticule mark.

5. Analog Pitch Signal.

Add the P-A circuits (Figs. 27, 28, and 29) for each channel. Adjust the series-connected 1k potentiometers (Fig. 29b) to approximately -.5v and -6v, respectively. Apply a 200 Hz signal to the auxiliary input (Fig. 26). Adjust the potentiometer at the input A2(29)-3, so that the output of the T(LF)/T(HF) comparator goes to 0v as shown in Fig. 30e. Make fine adjustments on the 1k series-connected potentiometer so that a transition from +8v to 0v occurs at T(HF) after the input pulse LB(27)-14, and the transition from 0v to -8v occurs at T(LF) after LB(27)-14.

6. Pitch Display.

Add the channel switch (Fig. 34). To obtain a visual pitch pattern on the face of the CRT, the two following adjustments must be made: (a) adjust the habitual pitch level (10k potentiometer at the input A1(34)-2 or A2(34)-2 to center the trace vertically on the screen. (b) Readjust the presentation selector to minimum persistence. The intensity is then readjusted so that the writing beam is just extinguished when the sweep is off, although the analog pitch signal is still obtained from the P-A circuit.

7. Vocal Intensity Display.

Add the vocal intensity circuits (Fig. 36). Turn the LOUD switch on. Measure the output A2(36)-6 when the maximum undistorted output is obtained at A2(26)-2. This signal should be created by a voiced utterance into the Mic. input, A1(26)-3. Adjust the cathode voltage of D5, Fig. 36, to this value. Set the anode voltage of D2 to -2v. Produce an input A1(26)-3, so that the output A2(36)-6 is between the two above-mentioned settings. With this input, adjust the potentiometer on the input A3(36)-3 so that the first three intensity lights are illuminated.

8. Earphone Gain.

Adjust the earphone gain as desired. The maximum gain adjustment produces a maximum undistorted output into a 20 Ohm load.